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ESTABLISHING DESIGN CRITERIA FOR THE INCORPORATION OF HIGHLY GLAZED SPACES INTO THE DOMESTIC BUILDING ENVELOPE

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ABSTRACT

This thesis investigates the design of domestic glazed spaces in the United Kingdom, by studying the effect of a range of variables on the thermal properties of glazed spaces, in order to achieve a thermally comfortable environment while minimising the use of energy for heating and cooling. Earlier research work on domestic glazed spaces has concentrated on optimising the design of the space as a mechanism for reducing the space heating load of the parent house. Computer based dynamic thermal simulation is used in this study as the method of assessment and the variables tested are; glazing type, orientation and the degree of integration of the glazed space with the parent building.

Unshaded, unventilated, and unheated, glazed spaces were found to be thermally comfortable for only a quarter to a third of the hours of possible use whatever the form, orientation or glazing type. Generally the higher the insulating value of the glazing the fewer the number of comfortable hours for all orientations and arrangements, due to discomfort being caused by high temperatures, even though the weather data used for the simulations only rose above 27°C for 25 hours during the course of the year.

Further studies showed that significant reductions in the number of hours experiencing high temperatures could be achieved by the use of buoyancy driven ventilation. The studies indicated that glazed spaces integrated into the house plan tended to experience high temperatures for long periods but that the peak temperatures were much lower than those experienced for shorter periods in the exposed spaces. The effect of ventilation on overheating was therefore more marked in the integral than in the exposed glazed spaces.

A study of the effects of roof shading blinds indicated that internal blinds had minimal effect in reducing high temperatures. External blinds had a greater effect than ventilation and a combination of external roof blinds and ventilation appears to provide the best strategy for the control of high temperatures.

Studies on space heating loads for the houses and glazed spaces indicated wide variations in the heating loads of the glazed spaces depending predominantly on the insulating properties of the glazing. In terms of the reduction in the space heating load for the parent house, the thermal simulation results predict very little change due to the presence of the glazed space.

A study on the effect of increasing the thermal storage properties of the floor construction of the glazed spaces, by substituting a clay tile finish for the original thin carpet layer, in order to reduce high temperatures proved inconclusive with minimal changes in the number of comfortable hours experienced.

An investigation of thermal comfort during the Winter indicated that low surface temperatures did not reduce resultant temperatures below the lower limit of the comfortable range in the glazed spaces, during the heated period.

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NOTATION

ac/h = air changes per hour
°C = degrees Celsius
°K = degrees Kelvin
kWh = kiloWatt hour
U value = the coefficient of thermal transmittance of a building element, measured as the rate of flow of heat in Watts through $1m^2$ of the building element when there is a temperature difference across the element of 1°K.

From the Tas treatment of solar radiation

θ = angle of incidence
θ_t = angle of refraction
α_p = absorptance at a point within a construction
$\alpha_{p\ ext}$ = absorptance at the outside surface of a construction
$\alpha_{p\ int}$ = absorptance at the inside surface of a construction
$\alpha_{i\ ext}$ = external solar absorptance of the component
$I_{i\ dir}$ = direct solar radiation [Watts] incident on a surface
$I_{i\ sky}$ = diffuse solar radiation [Watts] incident on a surface from the sky
$I_{i\ gnd}$ = incident ground reflected solar radiation [Watts] incident on a surface
n = refractive index of a layer
$r_{p\ ext}$ = thermal resistance at the outside surface of a construction
$r_{p\ int}$ = thermal resistance at the inside surface of a construction
t_{perp} = transmission of solar radiation perpendicular to the plane of incidence
t_{para} = transmission of solar radiation parallel to the plane of incidence
$q_{i\ sol\ int}$ = solar radiation [Watts] absorbed on the internal surface of the zone
$q_{i\ sol\ ext}$ = solar radiation [Watts] absorbed on the external surface of the zone

From the CIBSE correlation for stack effect ventilation

A_B = equivalent area for ventilation by stack effect only
Cd = discharge coefficient
g = gravitational constant
h_a = height of air column
Q_B = volume flow rate due to stack effect only
t_i = mean inside air temperature
t_o = outside ambient temperature
Δt = difference between t_i and t_o
$\overline{t}$ = mean of temperature t_i and t_o

CHAPTER 1

A Review of the Different Approaches to the Design of the Domestic Glazed Space

1.01 Introduction

The purpose of this study is to investigate, by computer based thermal simulation methods, the effect of a range of design options on the following;

- the domestic scale, glazed space as a thermally comfortable environment
- the amount of energy used in the heating of glazed spaces to a comfortable temperature
- any reductions in the space heating load of a house due to the presence of a glazed space
- the improvement of the thermal environment experienced in glazed spaces without the expenditure of energy

and to establish design criteria based on these findings.

The historical development of the glazed space

The intrinsic qualities of a glazed space are its visual appeal due to the high transmission of light through the glass and its provision of a sheltered, transitional space between outdoors and indoors. The temperature within the glazed space can often rise rapidly due to the effects of solar radiation, making it possible, in the colder months, to experience the sensation of being outdoors, while enjoying temperatures several degrees higher than ambient. Analysis of this phenomenon is provided in section 1.02.

The use of highly glazed spaces, to provide shelter with the benefits of light and warmth, has its origins in the glass houses, built in Europe in the sixteenth century. These glass fronted boxes were built to protect citrus fruit trees, unable to withstand the cold winters in the latitudes, greater than 50°, of northern Europe. On the land-owners' estates the glass houses developed into grander orangeries, large airy rooms, glazed on the south side and heated in the winter. In the latter half of the seventeenth century these became popular as rooms for entertaining, when the fruit trees were moved outside during the summer months. In this way the glazed space became a social room as well as a protective environment for plants.

With developments in the manufacture of glass and of wrought and cast iron during the eighteenth and nineteenth centuries, fully glazed structures became a possibility. Large conservatories, designed to let in the maximum amount of sunlight but also heated during the winter, provided the environment in which exotic plant species, brought from the colonies, could be successfully reared. Again the glazed structures also fulfilled a social role in the form of winter gardens and exhibition halls. The conservatories completed by Joseph Paxton at Chatsworth House in 1836, and the Crystal Palace again designed by Paxton, for the Great Exhibition in London in 1851, are both examples of these large scale, totally glazed constructions.

Due to increasing wealth among the middle classes, domestic conservatories also became popular during the nineteenth century. The conservatories were built as part of the original house design or were available as ready made components for addition to an existing house. Often they were not connected directly to the living rooms, to prevent the spread of damp and odours through

the house. The conservatories were heated or unheated and plants were chosen accordingly. Heating systems consisted of low level or underground pipework containing hot water or steam, fed from a solid fuel boiler. Ventilation was also provided in the form of opening vents at high and low level. These vents were controlled manually via a system of connecting metal rods arranged so that a handle turned at one point could open several vents in a single operation. In order to maintain acceptable temperatures for tender plants overnight and to conserve fuel, mats were placed over the glazed roofs to provide insulation. Similarly the heat storage properties of brick or stone walls along one side of the conservatory were utilised in attempts to maintain even temperatures. The masonry absorbed solar radiation during the daytime and emitted the heat as the air temperature fell. Figures 1.01 and 1.02 illustrate these measures.

During the first half of the twentieth century great social changes took place, partly as a result of the two World Wars. The scarcity of cheap labour needed to maintain the large glass houses together with declining fortunes resulted in the neglect, decay and demolition of many of the larger structures.

Sources for this section on the historical development of the glazed space; [Boniface,1982] [Marston, 1992] [Tressider and Cliff, 1986]

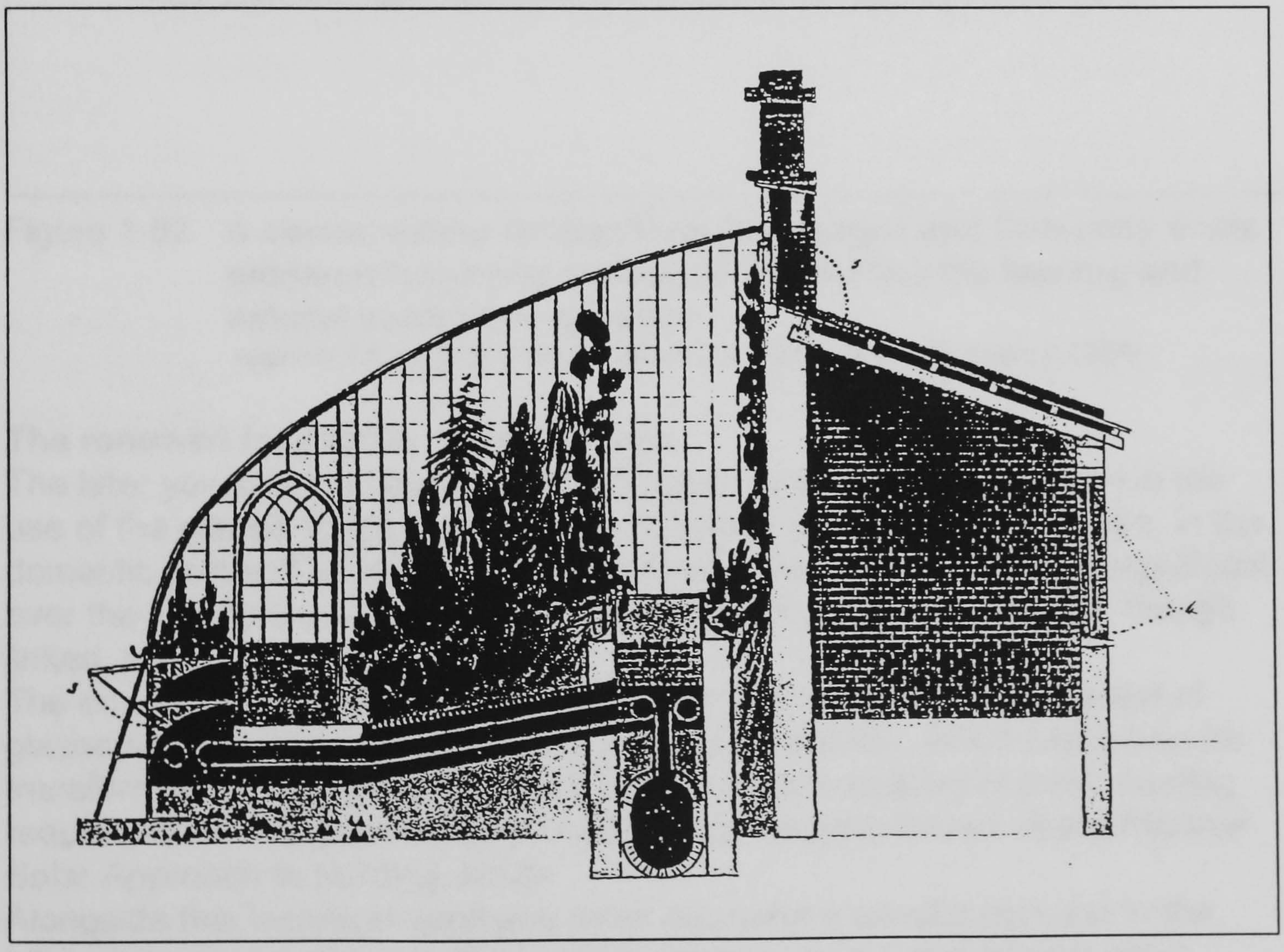


Figure 1.01 **A hot-house designed in 1818 by John Claudius Loudon illustrating the use of an underground heating system, a masonry rear wall and ventilators**
reprinted from Living Under Glass [Tressider and Cliff, Page 6,1986]

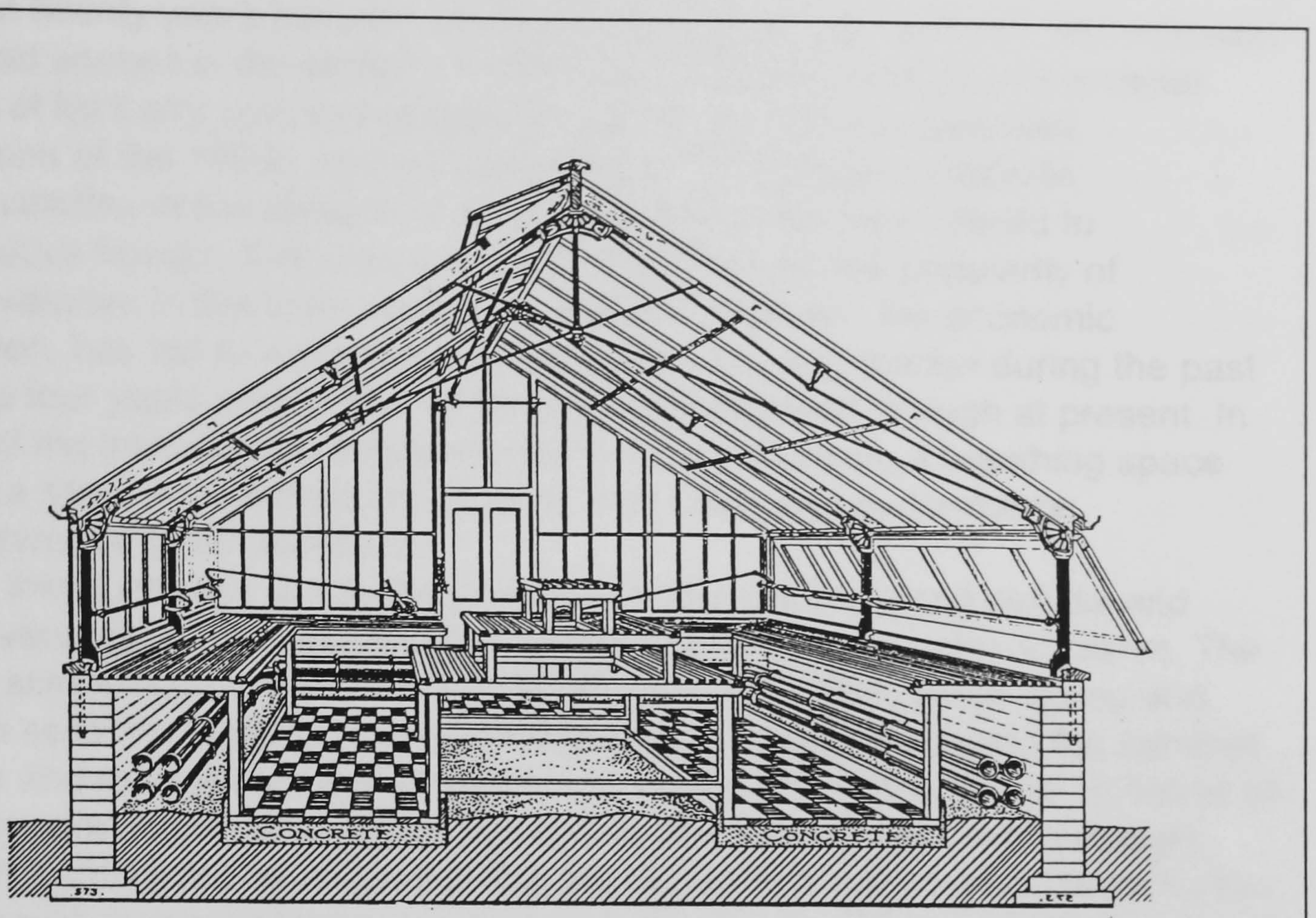


Figure 1.02 **A conservatory design from Messenger and Company's late nineteenth century catalogue illustrating the heating and natural ventilation systems**
reprinted from Living Under Glass [Tressider and Cliff, Page 6,1986]

The renewed interest in glazed spaces

The later years of the twentieth century have seen a renewed interest in the use of the glazed space in both public buildings and, on the small scale, in the domestic sector. The revival of the domestic conservatory has been significant over the last twenty years and has come about through two different, though linked, paths.

The energy crisis in 1973 created interest in the energy saving potential of glazed spaces, due to their ability to trap solar radiation, which could then be transferred into the house and used to offset space heating or water heating requirements. The practical application of this became known as the Passive Solar Approach to building design.

Alongside this technical approach there has been a parallel increase in the interest in glazed spaces among house owners. As a result of persuasive marketing by the conservatory supply industry, conservatories are now regarded as a luxury addition to the home. This development is very similar to the growth in popularity of the domestic conservatory during the last century.

The last twenty years has also seen architects experimenting with the inclusion of glazed spaces in the design or extension of houses, based on the visual appeal of light airy spaces and also on their energy saving potential.
At the end of the 1980s, some housing developers began to include conservatories in the designs of standard houses that they offered to prospective buyers. This was a result of feed back on the popularity of conservatories in the home extension market. However, the economic recession, has led to a downturn in the private housing market during the past three to four years and so this trend cannot be followed through at present. In terms of the inclusion of conservatories in house designs, a breathing space could be seen to be beneficial, to allow their value and performance characteristics to be assessed.
During these last few years, the problems of the use of glazed spaces and conservatories, built during the last decade or so, have become apparent. The glazed skin which provides a warm, light environment during the spring and autumn seasons leads to uncomfortably high temperatures during the summer months and excessively low temperatures during the winter months, in terms of the occupant's thermal comfort. The ventilation, heat storage and overnight insulation strategies developed during the eighteenth and nineteenth centuries, to cope with these problems, have been forgotten. As has the fact that many of the glazed spaces of the past were heated and that fuel and labour were cheap.
Conservatory suppliers are now offering increasingly complex devices, many requiring energy supplies, to control high and low temperatures so that the spaces can be used all year round. Consequently, a proportion of conservatories have become nett expenders of energy rather than mechanisms for reducing energy consumption for space heating.
This first chapter addresses these different approaches to the design of glazed spaces, looking in greater detail at the following;

- the physical characteristics of the glazed space
- the glazed space as an energy saving device
- the design and provision of glazed spaces as put forward by architects, housing developers and conservatory manufactures
- recommendations for the design of glazed spaces
- regulations governing the building of glazed spaces
- prediction methods for the thermal behaviour of buildings

1.02 The Physical Characteristics of the Highly Glazed Space

As mentioned previously, the temperature within a highly glazed space can often rise rapidly due to the effects of solar radiation. A small proportion of the short-wave thermal radiation from the sun, incident on the glazed envelope is reflected or absorbed but the majority of the radiation is transmitted through the glass. After the absorption of this short wave radiation by the surfaces of the space, the temperatures of the surfaces increase. The surfaces then emit long-wave radiation back into the space. Only a very small proportion of this long-wave radiation reaching the glazed envelope is transmitted through the glass as illustrated by Figure 1.03, below. The majority of the incident long-wave radiation is either reflected back into the space or is absorbed by the glass and a proportion radiated back into the space. Thus, the temperature within the glazed space increases significantly with only a comparatively small exposure to solar radiation.

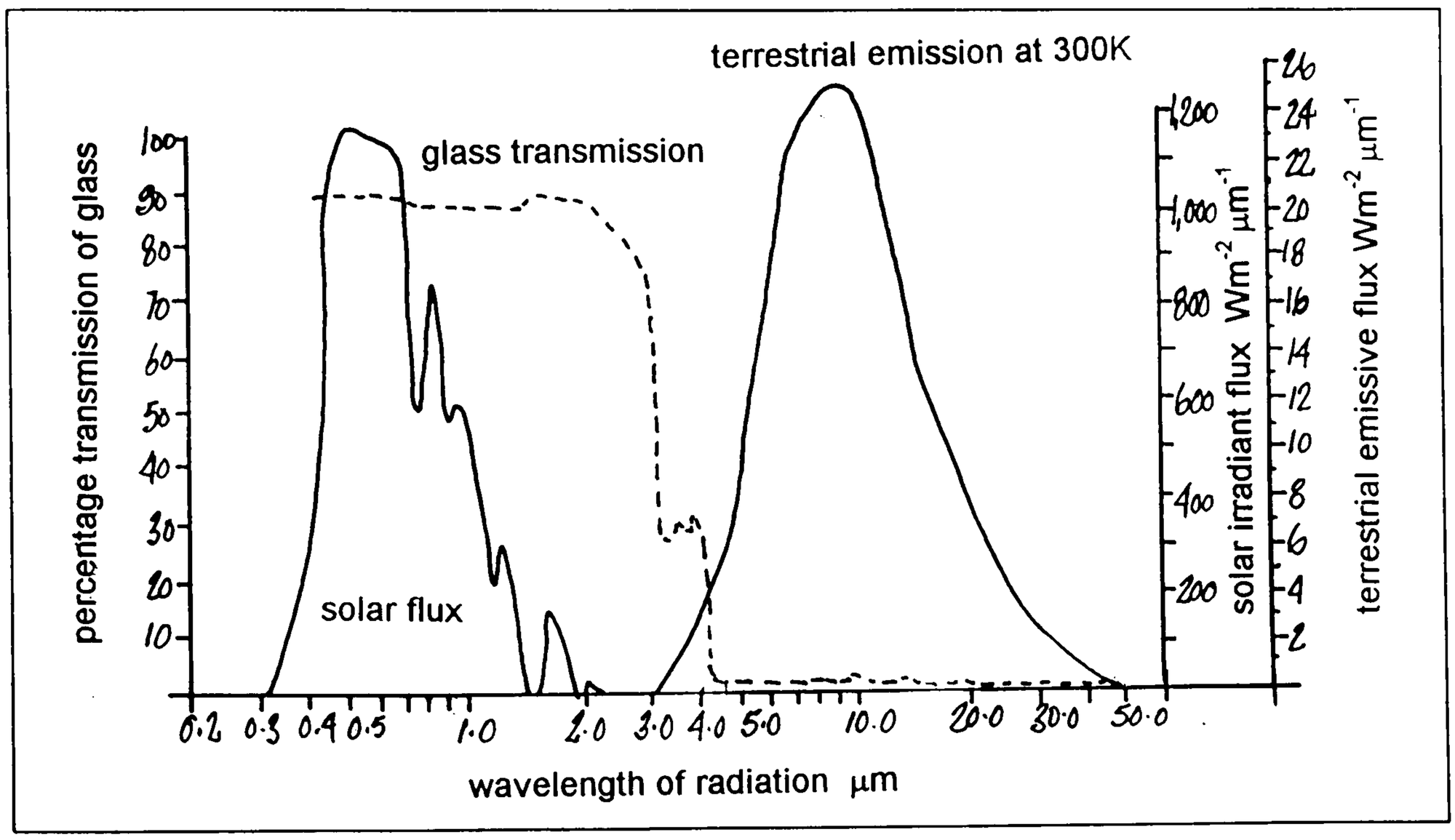


Figure 1.03 **Illustrating the relationship between glass transmission characteristics and the wavelength of solar radiation and terrestrial radiation at 300K**

As can be seen from Figures 1.04 and 1.05, overleaf the heat transfer processes which take place within a highly glazed space are complex and depend on the following factors;

- the intensity of incident direct and diffuse solar radiation
- sky temperature
- cloudiness
- external air temperature
- the reflection, transmission, absorption and emission characteristics of the construction materials of the external envelope and the floor and internal walls of the glazed space

- the thermal insulating and heat storage properties of the construction materials of the external envelope and the floor and internal walls of the glazed space
- the rate of introduction of external air into the glazed space by infiltration or by deliberate ventilation
- the thermal properties of the construction materials of adjoining rooms
- the air temperature as maintained by a space heating system in adjoining rooms
- the position and physical properties of buildings, hard and soft landscaping materials and planting surrounding the glazed space

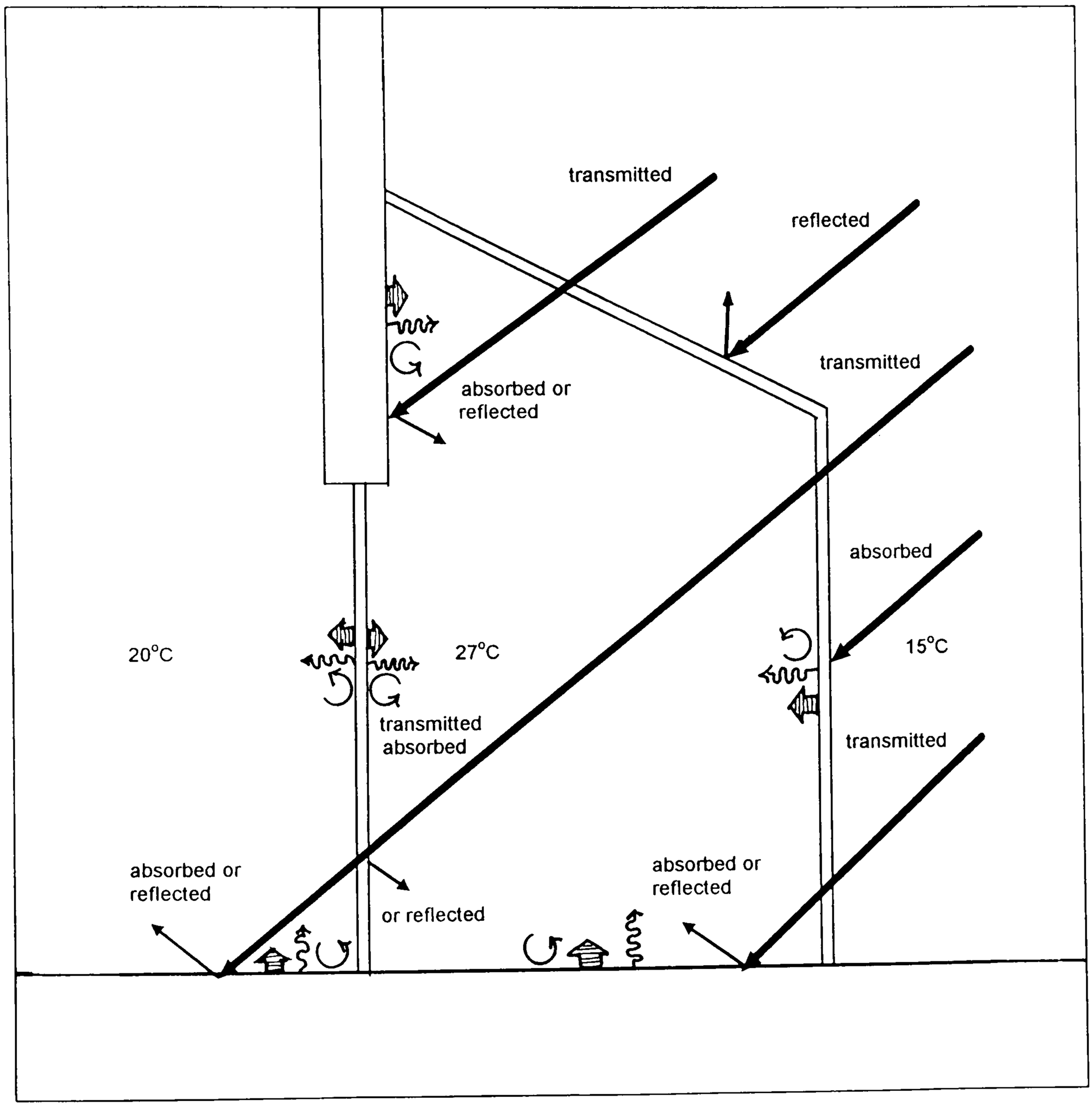


Figure 1.05 **The primary heat transfer processes taking place in a glazed space during daylight hours**

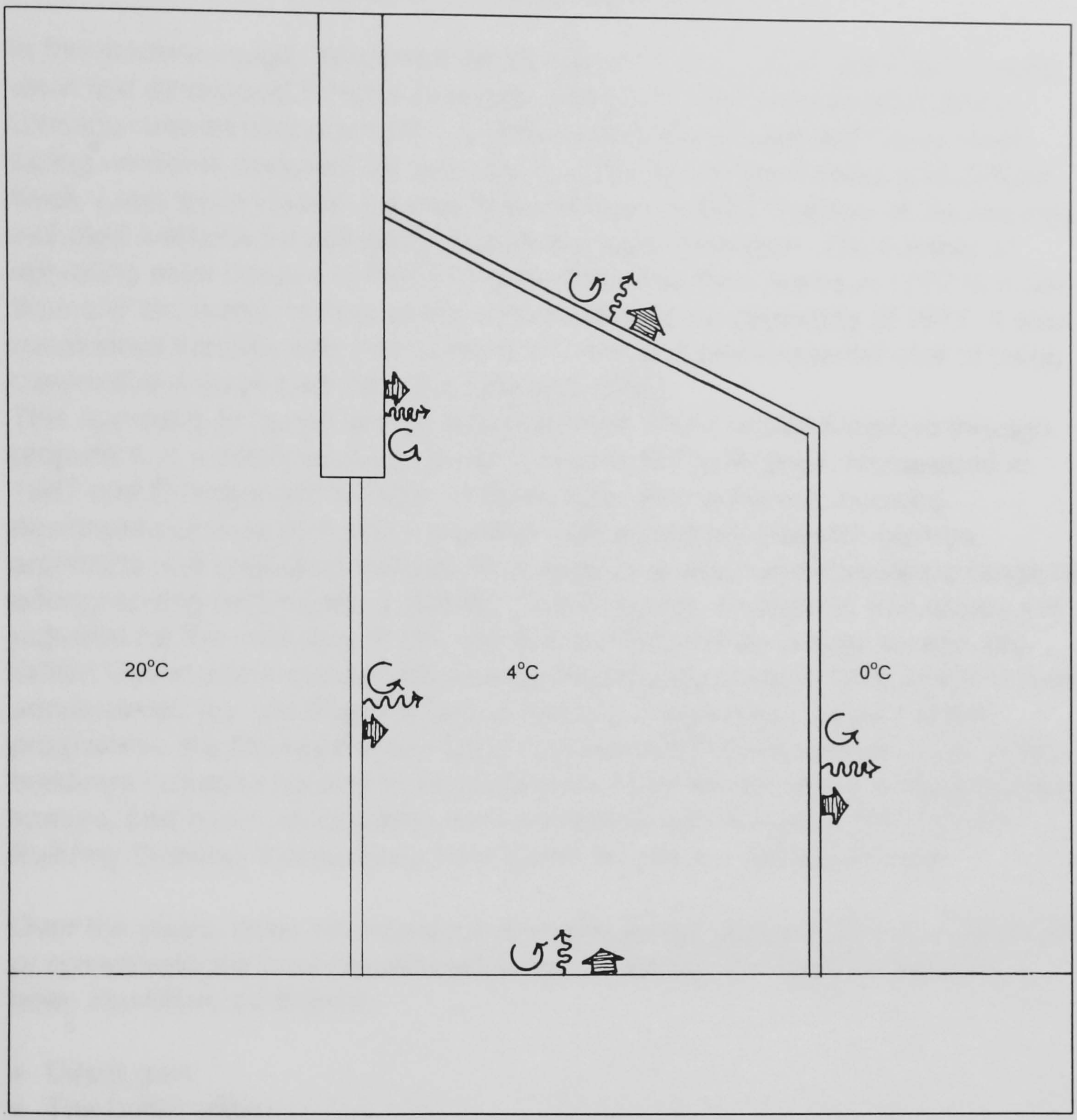


Figure 1.06 **The primary heat transfer processes taking place in a glazed space overnight**

conduction convection radiation

1.03 The Glazed Space as an Energy Saving Device

In the modern usage, 'passive solar design' and also 'active solar' techniques, were first developed in North America. The term 'Solar House' was used in Chicago newspapers during the 1930s, to describe houses with large south facing windows designed for solar gain, by the architects George and William Keck. Later experimental houses at the Massachusetts' Institute of Technology included methods for collecting and storing solar heat gain. The number of operating solar houses in the USA grew from less than twelve in 1972 to more than one thousand, built or under construction at the beginning of 1977. It was considered that this was due to the economic and environmental cost of using conventional fossil fuels for heat, [Watson,1985].
This approach to house design was promoted in the United Kingdom through projects and exhibitions such as those held in Milton Keynes; Homeworld in 1981 and Energyworld in 1986. In these and other schemes, housing developers or local authorities together with academic research centres, architects and engineers built pioneering houses which incorporated a range of energy saving techniques, including glazed spaces. In order to investigate the potential for the reduction in the use of fossil fuels as an energy source, the British Government created the Energy Technology Support Unit, which in turn administered the UK Passive Space Heating Programme. As part of this programme the Energy Performance Assessment Project was set up in which buildings including houses in which passive solar techniques, including glazed spaces, had been incorporated were monitored and reports written, [Solar Building Studies]. Conclusions from these reports are discussed later.

Over the years, three mechanisms by which glazed spaces such as sunspaces or conservatories were considered to reduce energy for space heating have been identified, as follows;

- Direct gain
- The buffer effect
- Preheating of ventilation and infiltration air

These mechanisms are described briefly below, the information being taken from the following sources;
Thermal Design of Conservatories for Solar Ventilation Pre-heating [Baker N,1985]
Passys II Final Report of the UK Consortium [Baker PH, et al,1993]
Modelling of Conservatory Performance [James and Dalrymple,1985]
Architectural Integration of Passive Solar Conservatories in Housing [Pascall and Yannas, 1985]
Energy Efficient Building, Chapter 12 - A Design Guide to energy efficient housing [Roaf and Hancock,1992]
The Potential for Sunspace Buffer Zones in Scottish Housing [Porteous,1985]
Solar Energy and Housing Design, Volume 1 [Yannas, 994]

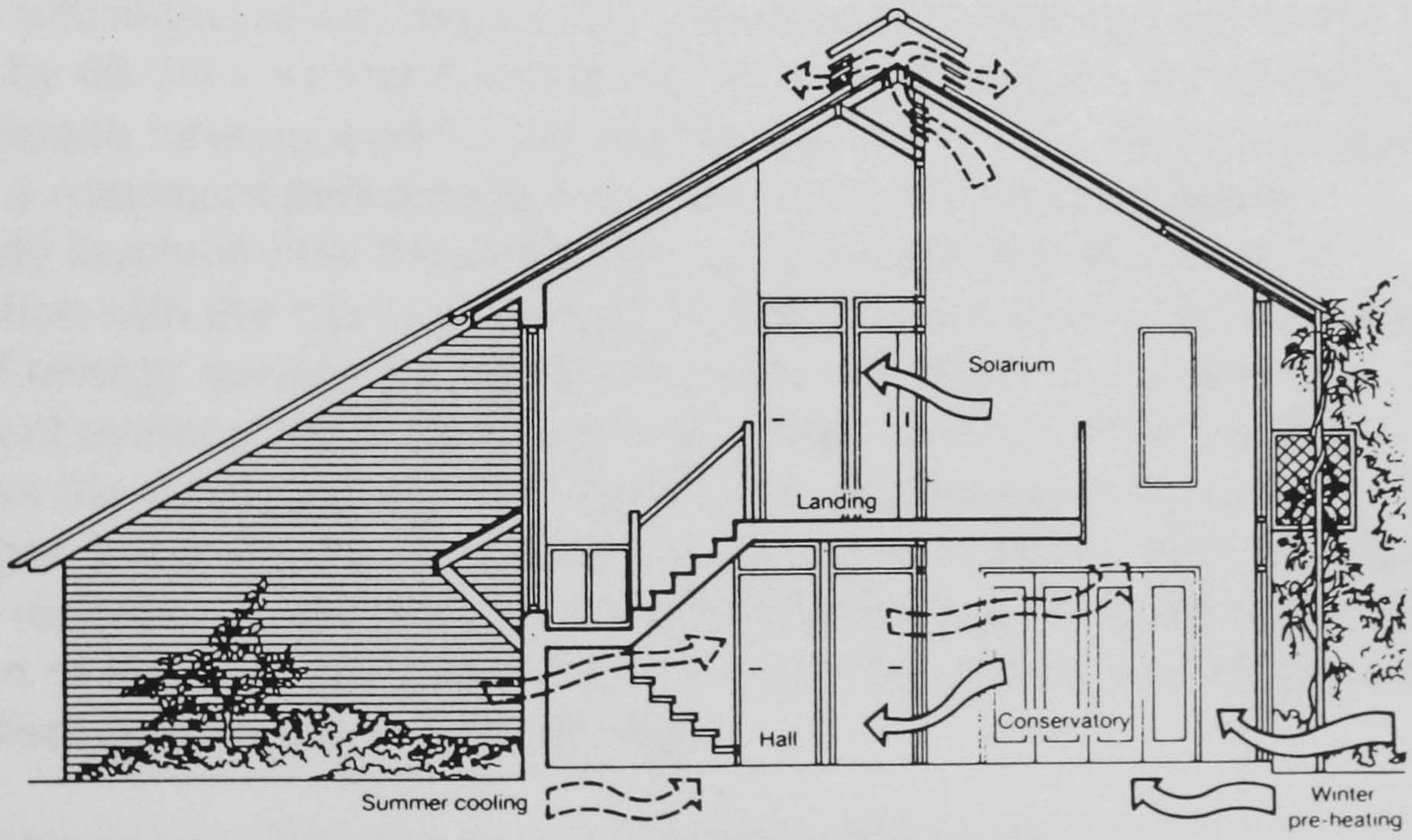
Direct gain

In the case of direct gain, solar heat gains in the glazed space, or sunspace, are transferred in a passive mode, by conduction, convection or radiation to other rooms in the house. In some instances movement of warm air is enhanced by the use of fans. Heat can be collected in rock stores or 'Trombe' walls of high thermal mass for later transfer to the rooms of the dwelling. These methods requiring the use of fans and / or heat exchangers move the system into the 'active' rather than the 'passive' mode. They also involve the expenditure of energy and the need for manual or preferably automatic controls.

The buffer effect

The air temperature within a glazed space will generally be several degrees above ambient, due to solar gain even from overcast skies and from heat loss from adjoining rooms. The conductive heat loss will therefore be less for the house wall(s) covered by the glazed space than for the exposed walls of the house. The glazed space therefore provides a buffer to the house against heat loss. This effect diminishes as higher levels of insulation are incorporated into the external fabric, as has occurred with successive revisions to the Building Regulations.

Preheating of ventilation and infiltration air



ECD's energy world house at Milton Keynes will feature solar ventilation pre-heating.

Figure 1.06 **An example of the use of a conservatory for solar ventilation pre-heating** reprinted from the Official Guide to the Milton Keynes Energy World Exhibition [Milton Keynes Development Corporation,1986]

If ventilation air for the house is introduced through a glazed space rather than directly from outside, its temperature will be a few degrees above ambient, thereby reducing the space heating load of the house. The significance of this saving will depend on the area of external wall covered by the glazed space and therefore the number of ventilation or infiltration openings bringing air into the rooms. If ducting is used then fans may be necessary to ensure a flow of air with the consequent problems of control, noise and the use rather than the saving of energy.

The design of a roof sunspace to provide pre-heating of ventilation air

A study was undertaken by the author of this thesis, at the request of the Hastoe Housing Association, into the design of a sunspace solar gain collector, situated in a roofspace. This is an example of the use of solar heat gain for the pre-heating of ventilation air. The report of the study entitled, 'The Thermal Performance of a Solar Ventilation Preheat System for Terraced Housing in Saffron Walden and Milton Keynes' is enclosed in Appendix A.

The system involved the warming of supply ventilation air to a terrace of four well insulated houses, by drawing the air in through a sunspace situated in the roof of one of the houses. The supply air was further warmed by being passed through a heat exchanger, carrying the exhaust air drawn from the houses.

The study involved the use of computer based thermal simulation in order to find the most effective design for the sunspace in terms both of glazing and of the type and arrangement of hollow blocks which combined the role of thermal store and extract ducts. Simulations predicted that the heat exchanger alone, [at 50% efficiency] would reduce the annual space heating load for the four houses by 46.3% and that a single glazed sunspace alone would reduce the annual space heating load for the four houses by 21.7%. With a combination of the two a maximum percentage reduction of 52.8% was predicted.

The study involved only the design of the sunspace and its effect, in conjunction with the heat exchanger, in reducing the space heating load. In terms of energy saving, the additional use of electricity to run the fans, in the air movement system, would need to be deducted from predicted savings, in order to assess the running costs. The capital and maintenance costs of the heat exchanger, the extra cost of the sunspace in lieu of a tiled, standard roofspace and the reduction in heating plant would also need to be compared with the provision of standard heating plant and ventilation provision and any additional costs offset against the energy savings.

The implications of a sunspace as a habitable room

When a roofspace is used as a collector of solar heat gain, as described above, the choice of glazing materials and the type and disposition of thermal storage materials is based on maximising the output from the sunspace. Decisions are restrained only by cost. If the sunspace is designed to be part of the living area of a house, then these decisions are also governed by aesthetics and user requirements. Materials of high thermal capacity, providing thermal storage, may be used in the floor and solid wall construction. However the floor may be

covered by carpets and shaded from solar gain by furniture, walls will be decorated and similarly shaded, thus reducing the heat storage potential of the sunspace. Transfer of heat from the sunspace to the house by the convection of warmed air through windows and doors between the two areas depends very much on occupant behaviour. For instance the wish to restrict pets, small children or noise to one area of the house, could undermine such a system, [Architects' Journal,1991] [Vaughan and Jones,1993].

A further problem is the lack of co-incidence of the timing of demand for space heating and the time when solar gain in a glazed space will peak, on a daily and a yearly basis. The daily, highest achievable levels of solar gain, occur immediately after noon, and are therefore useful in offsetting space heating requirements during the daytime and particularly around mid-day and early afternoon. Thermal storage is necessary if the heat is to be retained to offset the space heating requirements of purely evening occupancy.

Higher ambient temperatures and higher levels of solar radiation during the Summer reduce the demand for space heating, yet the sunspace which is geared towards maximising solar gain during the Spring and Autumn will still be acting as a collector. Thermal simulations of the roof sunspace, discussed above, predicted temperatures of almost 60°C on a July day of very high solar radiation and over 30°C on a fairly overcast day. If such a sunspace is also to be used as a room for human occupancy then measures to dissipate unwanted solar gain would be necessary.

Conclusions on the use of a glazed space as an energy saving device

From this study of a roof sunspace it can be seen that the functions of a glazed space as a collector of solar gain are in conflict with those of a glazed space as a habitable room.

Analysis of the monitoring results of the houses with glazed spaces for the Energy Performance Assessment Project by Nigel Vaughan of the Welsh School of Architecture led him to the conclusion that most of the houses studied used less space heating fuel than houses of similar size, design and construction, but without conservatories. However the cost of the energy saved, mainly by the buffering effect, was very small when compared to the construction cost of the glazed space or conservatory and therefore the amenity value of the conservatory as additional living space has to be taken into account when justifying the cost. [Vaughan and Jones, 1993]. However the design of a glazed space as a collector of solar gain compromises its use as a living space as shown by the roof sunspace study.

In his analysis of the Energy Performance Assessment Project data, Simos Yannas concludes that none of the examples cited in Volume 2 of his book, 'Solar Energy in Housing Design' offers conclusive evidence of energy savings due to the presence of a conservatory, [Yannas,1994].

1.04 The Design and Provision of Glazed Spaces as Put Forward by Architects, Housing Developers and Conservatory Manufacturers

A survey of Architects

A survey of experience, opinions and available technical information about glazed spaces in domestic architecture, within the building industry, was undertaken in order to provide background information for this thesis. Letters inviting architects, building contractors and developers to take part in the survey were sent to several trade journals and were published in 'Building Design' and 'Building', March 1992, and in the 'RIBA Journal' [Royal Institute of British Architects], May 1992. This chapter deals firstly with the responses from Architects. A copy of the questionnaire is included in Appendix B

Nine architects agreed to take part in the survey and six of these returned completed questionnaires. Of these six, only one architect sent details of a housing development which included conservatories in one of the house types. The other five respondents had experience of adding glazed spaces to existing houses or of designing individual houses with a glazed space included in the design.

The housing development, which was in the process of construction, consisted of 44, terraced family houses on a 1.38 hectare site in Edinburgh. The 5 person, house type of 155 m^2 total internal floor area had in addition, a single storey, lean-to conservatory of 18 m^2 internal floor area. The conservatory covered the whole of the ground floor rear elevation of the house and so provided the means of light, ventilation and external access to the kitchen and dining room.

As the houses were arranged in terraces, a solid wall divided each conservatory from its' neighbour. The front wall was double glazed and had an opening door and three top hung opening windows. The roof was double skin, polycarbonate sheeting and had no vents. The architect, Tony Kneale, felt that from his experience overheating would not be a problem in the conservatories due to their north-north-west orientation and the proximity of a belt of mature trees growing on an embankment, approximately 10 metres distance away. No heating appliance was installed in the conservatory. As the first three houses of this type had only just been occupied, there was no feedback from the occupants on the performance of the conservatories in terms of their use as additional living space.

Four other Architects supplied information about glazed spaces which they had designed as extensions to existing houses. The conservatories had been added for their amenity value with any energy saving benefits being a secondary issue.

One architect, Frank Hawes, added south facing glazed spaces to two houses which he had occupied and found them to be the most used room in the house, so long as measures were taken to avoid overheating. The conservatories were used as sitting room, dining room and playroom. He found them habitable without heating from March to November / December. High level opening lights

[manually operated] were left open from May onwards, the resulting natural ventilation preventing overheating. The conservatories were built as tall as possible to encourage this cooling effect. Double skin patent glazing was used for the roofs. The floors were concrete slab with a quarry tile finish. The walls were only partly glazed with inserted windows and doors rather than being fully glazed, as another measure to avoid overheating. A third glazed space in the form of a porch on the north face of the house has also been found to be acceptable and prompts the architect to suggest that south facing is perhaps not the best orientation for a glazed space.

Two other architects who added glazed spaces to existing houses for clients stressed the importance of avoiding overheating. One architect, A. Burton, pointing out that design guidance was lacking and that maximising solar gain, recommended from an energy saving point of view, leads to overheating and loss of amenity. The second architect, James Lewis, also felt that there was very little authoritative design guidance and had found problems convincing clients of the need for the measures to avoid overheating. He specified heat activated pressure arms for automatic window opening and closing.

Another architect, Raymond Honey, added a small, south facing conservatory to his own house in order to provide amenity, to give a sense of space and to house plants. He has found it highly satisfactory in these terms. The double glazed conservatory has a single leaf external door, two side hung windows, openable fanlights around all five sides and also a raised central flat roof area with pole operated, opening vents on two sides. Overheating problems appear to have been avoided by this ventilation provision.

A sixth architect, Richard Parnaby, incorporated a glazed space into the design of a 183m^2, 4 bedroomed house, both for the additional amenity and for energy saving benefits. The south facing conservatory is accessible from the kitchen, dining room and sitting room, via glazed double leaf doors. The lean-to conservatory roof abuts the house just below house eaves level. Windows from the upstairs circulation area and the main bedroom open into the conservatory. The concrete floor slab is finished with quarry tiles and is designed to act as a heat store as is the solid wall area dividing the conservatory from the house. There are two small top hung ventilation openings at the highest point in the roof. Warm air is drawn out at the upper level of the conservatory, controlled by a thermostatic damper and passes, together with air extracted from the kitchen and bathroom, into a heat pump/heat recovery unit to heat incoming ventilation air. No feedback on the conservatory was available as the house had not been occupied at the time of the survey. Richard Parnaby put forward the view that owners were more likely to heat a conservatory if it was integrated into the design of the house rather than being an attached space with limited access.

The seventh respondent, C. Cooper has spent several years studying passive solar house design and attempting to put his findings into practise. In 1982 he

designed a house for his own use, based mostly on published data from North America, using the recommendations which were appropriate to the UK climate. The design incorporated a south facing, single glazed space, enclosed within the house on three sides and with one external glazed wall and a glazed roof following the line of the house roof. The first floor landing opened onto the conservatory via sliding glass panels, allowing the transfer of warm air from the conservatory into the house, cooler air from the house entering the conservatory at lower level via doors. It was also intended that this air circulation pattern could be used in summer in order to promote cooling, the warm air rising through the conservatory passing out of the building through high level roof vents. However, these roof vents were not installed, due to cost restraints. The floor is a heavily insulated tiled concrete slab.
The house was monitored by ETSU contractors in order to establish the protocol for the Energy Performance Assessment programme on monitoring built examples, mentioned previously. From analysis of the monitored data the EPA study estimated the contribution from solar heat gains, [via windows and conservatory] to the space heating load for the house, at approximately 17%, based on the space heating loads for the period September to May. Over the whole year the contribution of solar heat gains to providing thermal comfort is considered to be nearer to 25-30% of the total requirement.
[Yannas,1994, Vol. 2]

Further evidence of architects' involvement with the inclusion of glazed spaces in housing can be seen from the Passive Solar Design Studies, mentioned previously several of which describe houses designed by architects for their own use. The three Milton Keynes housing exhibitions, Homeworld, 1981, Energyworld, 1986 and Futureworld, 1994 also included several houses designed by individual architects which incorporated highly glazed facades or conservatories in the design. A more dramatic example is that of the recently completed Hauer/King house designed by the Future Systems architectural practice in which the whole of the sloping south-east facing facade is glazed.
[Architects' Journal,1994]

Housebuilders and developers responses to glazed spaces in house designs

Although the last twenty years has seen great increases in homeowners installing conservatories as extensions or luxury home improvements, this trend has not followed through to the inclusion of conservatories in housing developers' standard house types, to any great extent. As mentioned previously many of the house types built at the housing exhibitions in Milton Keynes incorporated glazed spaces in the design, particularly as an energy saving feature in the earlier two exhibitions, but again the use of conservatories on a large scale has not fed through to the speculative housing market.

The Market Research survey, 'The Marketability of Passive Solar Homes', [London Business School, 1988] studied the way in which innovations in

housing design were diffused through the speculative housing market in order to predict the take up of ideas on passive solar design by developers. The survey shows that many innovations have occurred, such as central heating, double glazing, cavity wall insulation and fitted kitchens, led by the home improvements market. Developers were reluctant at the time of the survey, 1984, to incorporate an expensive item such as a conservatory into their designs without knowledge of what the public response would be. Also at that time, there were doubts over the supply and installation of suitable products which could be adapted to a range of house types.

There were however, signs of developers' increasing interest in conservatories in the early years of the 1990s, before the onset of the economic recession. An article written in the 'Housebuilder' journal, [Housebuilder,1992] entitled 'The warm feeling of extra space', reports on the opinions of several developers to the use of conservatories in their house types. Bovis South West currently conducting their own research into the home improvements market, have found that "early indications show that conservatories account for a significant part of the add-on market."

Bovis Homes, Northern Home Counties office has already built conservatories as standard, on two of its house types in a development of four bedroomed terraced town houses. Their Regional Sales and Marketing Director, is quoted as saying, "Conservatories continue to be popular on up-market houses, and when the market comes back we believe that they will be a definite sales plus."

Other developers are more circumspect; the Marketing Director of Prowting Developers stated "'We specialise in selling inexpensive mid-market properties and everyone wants discounts at the moment. Putting in a conservatory would not be worthwhile for us. If conservatories became in fashion (as before the recession) then we may rethink our ideas."

Seamus Grant, Sales Director of Martin Grant Homes stated, "When housebuilders are considering adding facilities such as a conservatory to a property the overriding question has to be 'is it cost effective?' " He adds, "Builders may not get their money back on the purchase price, but they may sell the house three months earlier, and save money on interest charges."

However, Martin Grant Homes are considering adding conservatories to their larger executive style homes, as they believe that they will enhance the accommodation. They feel that, "conservatories only lend themselves to certain houses, depending on the aspect, the size of the plot and the amount of privacy, and that to look good they should form an integral part of the building. The article concludes; "When confidence is re-established and the [housing] market moves, the conservatory could very well re-assert itself as the quality sales aid it was fast becoming before 1989."

Only one Housing Developer responded to the questionnaire as mentioned earlier. R. Pearson of Crest Homes Plc sent plans and information regarding a development of four-bedroomed detached houses, [internal floor area 125 m^2]. The houses were at the planning stage and it was the developers intention to offer a conservatory, of 10 m^2 floor area, as an additional extra. The single

storey, square conservatory fits into the corner of the house plan adjoining the kitchen/family room and the lounge. Sliding glass doors from both these areas give access to the conservatory, and both rooms have windows in other external walls. The conservatories have been designed and detailed by a conservatory manufacturer but do not contain any mechanisms for controlling excessively high or low temperatures, condensation or glare. No details are given regarding the design and construction materials of the conservatory. The developer intends to incorporate conservatories in future developments, if they prove successful.
The response, included earlier in this chapter, from Tony Kneale gives information about a private housing development in Edinburgh where conservatories are include in the design of the houses.

An interesting, but disturbing footnote, to the inclusion of conservatories in house designs in the private sector, was included in a trade newspaper article entitled 'Collision Course on Regs' [Building Services and Environmental Engineer, September 1993]. This reported opposition to the proposed changes in the Building Regulations, Part L Conservation of Fuel and Power, due to come into effect in 1995, as follows; "A task force sponsored by the Department of Trade and Industry has recently presented to the Prime Minister a series of proposals that include abolition of that part of the Building Regulations[Part L] governing standards of energy efficiency in new houses. While only 8% of the 120 or so responses to Consultative document, analysed by the Department of the Environment thought that standards should be reduced, the task force argues that the regulations put an unfair burden on house builders who are under pressure to reduce costs because of the recession in the industry. Many housebuilders would prefer to do away with energy saving features, such as insulation, which they say do not sell houses, in favour of more desirable features like conservatories and kitchen fittings."
The task force were not able to influence the insulation requirements of the revised Building Regulations [Part L] which eventually came into force in mid-1995. However, the lobby group's lack of recognition for the need to reduce space heating energy consumption in new housing, which they say reflects housebuyers requirements, is of concern, particularly with the possibility of owners heating their conservatories, resulting in them becoming nett energy consumers rather than energy saving devices. [Chu and Oreszczyn,1992] and [Oreszczyn,1993].

The conservatory supply industry
Although this thesis is mainly concerned with glazed spaces as an integral part of new housing, the experience gained from the conservatory supply industry is relevant even though it deals predominantly with the home improvement market. The increase in home ownership and in disposable income, available for house extensions and home and garden improvements, has led to rapid expansion in the domestic conservatory industry during the last twenty years.

A newspaper article, [Guardian, 1994] talks of 'a market undergoing a massive resurgence - home owners are spending more than £200million per year on conservatories'.
Conservatory designs offered range from basic shapes with low-pitched roofs, through replica 'Victorian' styles to complex custom-built enclosures. Framing systems are in wood, aluminium or uPVC [unplasticized polyvinyl chloride] and glazing is single or double, with low-emissivity coating to the inner leaf often offered to improve heat retention. Twin or triple skinned polycarbonate sheeting is also an option, as a lightweight roofing material with better insulating properties than single glazing.

Over the years problems of condensation and overheating, have become apparent with many installed conservatories. There also seems to have been an expectation from owners that the conservatory should be warm enough to use as a living space, all year round. In a presentation at Glassex'94 exhibition [Glass and Glazing Products, 1994], The secretary of the Conservatory Association, Peter Moon, said that, "A conservatory is one of the most frequently used rooms in a house, so why is it that manufacturers and retailers still avoid the issue of designing conservatories that are environmentally friendly to the end user ?" He also felt that either facilities for controlling the environment should be supplied as part of the basic product, and not as optional extras, or the conservatory should be designed in such a way as to accommodate the reasonable expectations of the purchaser with regard to the internal environment. Peter Moon was basing his criticisms on information gained from a market research survey of almost 2000 conservatory purchasers, [Moon, 1991], produced by the Conservatory Association for the Energy Technology Support Unit in association with the Bartlet School of Architecture.

Conservatory manufacturers have responded to criticisms by offering glazing systems, double or double with a low emissivity coating, with better insulating properties than single glazing and also incorporating small opening lights at eaves level to provide ventilation. Openings in the roof are more problematical due to the difficulty of making them watertight. At the 1994 Glassex exhibition several manufacturers featured "fully weatherproofed" roof vents for polycarbonate sheet roofs, whereas these had been noticeably absent at the 1993 event. One industry body recently issued a guidebook, [Glass and Glazing Federation, 1994] for people considering buying a conservatory, which describes a conservatory as a, "Versatile home extension providing a bright and sunny room with a completely different atmosphere to the rest of your house perfect for leisure and relaxation." The pamphlet describes the effect of orientation on the internal environment to be expected, summed up as follows,;

- Against a South facing wall - the location with most sun all year round, particularly comfortable in winter, though will get hot in the summer. Efficient ventilation will reduce the temperature sufficiently for human occupation but probably not for plants.

- West facing - will receive a lot of sunlight particularly on summer afternoons and evenings. It will receive less direct summer sunlight therefore this orientation may be better for plants than south facing.
- East facing - exposure to cold Easterly winds but would receive early morning sun and would therefore be useful as a breakfast room.
- North facing - would be without direct sunlight for about three months in winter, therefore it would need more efficient heating and insulation for winter use. It would provide a warm and bright environment in summer.

The guide concludes, "Whatever position, the conservatory will provide a cheery and pleasant atmosphere, providing heating and ventilation are carefully considered."
The guide also indicates the importance of high and low level ventilation in releasing hot air from the top of the conservatory to be replaced by a flow of cool air from low level, in order to combat overheating. Extractor fans or circulating fans are put forward as a means of coping with overheating likely to be experienced in a south facing conservatory. In terms of glazing, the guide recommends double glazing as essential if the conservatory is to be used for relaxation all year round. Low emissivity glazing is recommended for further heat retention. However the guide does not relate glazing type to orientation or mention that overheating could be exacerbated by increasing the insulation properties of the glazing. Internal blinds to the walls and roof are recommended to reduce glare. The guidebook also suggests heating a conservatory by extending the house heating system.
Many conservatory manufacturers show radiators or underfloor heating systems in their product catalogues. Some catalogues also show air conditioning units and these units are also appearing in home improvement catalogues aimed at conservatory owners.
An article in the Housebuilder journal on the trends in conservatories, [Housebuilder,1992], states that, "As more and more people see the conservatory as an extension to their living space rather than simply an adjunct to their garden, the manufacturers are upgrading their glazing, heating and lighting systems, as well as developing new products."
The conservatory industry is obviously making great efforts to improve their products in line with the concepts of year round comfort expressed in their advertising literature. However their recommendations often involve the use of energy for heating and ventilating which could possibly be avoided if more technical information on the effects of orientation, natural ventilation and glazing materials on the thermal performance of these spaces were available.

1.05 Recommendations for the design of glazed spaces

The range of sources

Recommendations are available for the design of domestic glazed spaces based on their perceived use as a living room or as an energy saving device. These recommendations come from a wide variety of sources including the following;

- Books, newspaper and magazine articles aimed at prospective purchasers
- Guidelines from the conservatory and glazing industry
- Reports on the monitoring of houses with glazed spaces. [Solar Building Studies] [Yannas,1994]
- Results of the Passys II studies on test cells, devised to investigate energy saving potential, but including investigations of thermal comfort. [Baker PH et al,1993].

Type of glazing

The recommendations for the glazing of a glazed space, to be used as a living room, suggest that the higher the insulation value of the glass the more thermally comfortable the space will be. Their is often an assumption in the conservatory industry and in books aimed at prospective owners that the conservatory will be heated and that double or low emissivity glazing should be installed in order to reduce energy consumption, [Marston,1992] [Glass and Glazing Federation,1994] [Glass and Glazing Products,1994]. Multiple layered polycarbonate sheeting, is also recommended for roofing due to its good insulating properties and its lightness which reduces construction costs.

Orientation

Again recommendations on orientation are based on the viewpoint of the author of the information. The Glass and Glazing Federation handbook discusses the benefits and implications of all orientations in very general terms, as previously mentioned, [Glass and Glazing Federation,1994].
Several of the Architects, in responding to the questionnaire, Chapter 1.04, suggested that a northerly or easterly orientation would be preferable on the basis of thermal comfort in the Summer. Recommendations on orientation based on the study of the energy saving potential of conservatories suggest that a southerly orientation is preferable. [Yannas,1994]

Ventilation

Most sources recommend the necessity for ventilation in glazed spaces in order to reduce summertime overheating, [Glass and Glazing Federation,1994] [Roaf and Hancock,1992, Chapter 12] [Marston,1992] [Yannas,1994].
High level openings are generally recommended, though not all sources mention the need for additional low level openings. These provide the means of completing the cycle in which warm air, rising and escaping at high level, draws in replacement external, cooler air at low level.

The report on the Passys II test cell experiments, which included a glazed space with a window in the side wall, states that "improved ventilation would appear to offer the most effective means of overheating control." The report also recommends that an openable rooflight would probably provide higher exchange rates than a side window and would therefore be more effective in controlling overheating, [Baker PH et al,1993].

Cooling devices

The Glass and Glazing Federation guide suggests that extractor fans or circulating fans may be necessary to cope with overheating likely to be experienced in a south facing conservatory, [Glass and Glazing Federation,1994]. 'The Book of the Conservatory' extends similar advice on cooling mechanisms to include the installation of an air conditioning system, involving refrigerative cooling and humidification, [Marston,1992].

Shading

The Solar Building Studies include several examples of conservatories or glazed spaces which utilised different shading devices. The glazed areas of Copper Beech House were shaded during the summertime by a large beech tree. In Autumn the tree shed its leaves allowing the low angled sun to reach the interior, [Solar Building Studies, Report no. 2]. Unfortunately shading of glazed spaces by deciduous trees cannot often be arranged due to the time taken for trees to reach maturity and the problems of subsidence caused by roots of trees and shrubs in clay soils. Trees need to be very tall and / or very close to shade roof glazing from the summer sun.

Conservatories in the Willow Park housing development were supplied with internal blinds as a means of solar control, but operation created a problem for some owners and they were left closed, [Solar Building Studies, Report no.16].

The Passys Study investigated the effect of aluminised solar reflecting blinds fitted to the underside of the conservatory roof on conservatory overheating. The study found that the use of the internal roof blind increased conservatory air temperatures above those expected. The authors suggest that a possible mechanism for this increase, is that the proportion of solar radiation which is normally reflected and passes back out of the conservatory if there is no blind, is absorbed by the blind and the energy emitted as longwave radiation to other surfaces within the conservatory, [Baker PH et al,1993].

The MSc thesis [Swann,1991] using computer based thermal analysis, found that external blinds could reduce high temperatures in glazed spaces but that internal blinds could not.

A partially solid roof or deciduous climbing plants have also been proposed as methods of reducing high temperatures, [Marston,1992].

Heating

Although, from the evidence of the limited survey, Architects accept that glazed spaces should not be heated, this approach is not accepted by other groups.

The assumption by the conservatory supply industry that conservatories will be heated has already been discussed.
While some householders do not expect to be able to use a conservatory all year round [Solar Building Study no.16] others use heating to provide a comfortable environment during the cooler months. [Chu and Oreszczyn,1992] and [Oreszczyn (1)and(2),1993]. Simos Yannas suggests that this could increase the annual heating bill for a new, well-insulated dwelling by between 50-100%. This assessment is based on a house of 110m^2 total floor area, with a single storey, lean-to conservatory of 12m^2 floor area and based on index calculations for Birmingham, [Yannas,1994,p106].
A newspaper article on conservatories states that double glazing "has the underlying premise that you will also have radiators to provide the heat to be kept in. These can be run off the existing central heating system, at little extra cost," [Observer,1992]. The heating of conservatories is discussed further in section 1.06 on regulations governing the building of glazed spaces.

Form and construction of the glazed space
In terms of the form and construction of the glazed space Simos Yannas states, "Compact geometric forms and a moderate glazing area are recommended to control Winter heat loss and Summer solar gain," "Exposed [or tiled] masonry elements should be provided to control summer temperatures." and "Insulating the floor and part of the roof [and side walls for attached conservatories] provides a higher temperature in the Winter." [Yannas,1994,]
The use of thermal mass in order to reduce summer overheating is mentioned, in the book, 'Energy Efficient Building' [Roaf and Hancock,1992, Chapter 12]
The MSc thesis [Swann,1991], concluded that, "The temperatures achieved within a conservatory are influenced far more by the choice of either single or double glazing for the external walls than by the thermal response of the solid walls dividing the conservatory from the house. The slow response, single glazed combination providing approximately 1.4 times as many comfortable hours as the fast response, double glazed combination for any of the three conservatory configurations tested, [one, two or three dividing walls]."

The effect of the glazed space on adjoining rooms
Nigel Vaughan noted "the necessity to isolate the conservatory from the rest of the house so that extremes of temperature in the glazed space do not affect temperatures in the rooms, particularly if a build up of heat is required to fulfill the conservatory's passive heat source role," [Vaughan and Jones, 1993].
Simos Yannas noted that there could be increases in energy usage, resulting firstly, from the reduction in solar gains and daylight in habitable rooms due to the conservatory envelope and secondly, from the possibility of doors and windows facing into the conservatory being left open during the heating season, [Yannas,1994].

1.06 Regulations Governing the Building of Glazed Spaces

In the United Kingdom building work is regulated by two main procedures under the jurisdiction of the Local Authority. Before building work can take place it is first necessary to obtain Planning Permission. During this process the Local Authority Planning Department considers whether the proposed development is suitable for its location, in terms of use, size and appearance. Secondly, the proposed building work has to be granted Building Regulations Approval. In this process, the Local Authority Building Inspector has to be satisfied that the proposals comply with the requirements set out in the Building Regulations concerning such matters as structural stability, conservation of fuel and power, ventilation, fire precautions etc.

Planning Regulations relevant to a conservatory

If a new house with a design incorporating a conservatory is to be built, then the granting of planning permission will be based on whether the design is deemed to be suitable for its location.

A conservatory built as an extension to an existing house would need to comply with the regulations governing extensions in general. Planning permission is not required if the proposed extension complies with limitations on the volume of the extension, its height and position relevant to the highway and to the boundary of the property and the area of the extension related to the area of the site. If the proposals contravene any of these limits then the design will need to be submitted for planning approval. [Department of the Environment, 1991]

Building Regulations relevant to a conservatory

If a conservatory is built at the same time as a house, the use of energy for heating the house and conservatory would be governed by Part L-Conservation of fuel and power (1995 edition), [Building Regulations, (6)].This edition includes clauses specific to conservatories for the first time, as follows;

> *A conservatory has not less than three-quarters of the area of its' roof and not less than one-half of the area of its walls made of translucent material.*
>
> *When a conservatory is attached to and built as part of a new dwelling:*
>
> *a. where there is no separation between the conservatory and the dwelling, the conservatory should be treated as an integral part of the dwelling,*

In this case where the conservatory is to be part of a house then the external fabric of the conservatory must comply with the Regulations, along with the external fabric of the house, in terms of limiting heat loss through the building elements. Areas of glazing are also limited but allowances can be made for the benefits of solar heat gains, if either the Energy Target method or the Energy Rating Method are used to show compliance.

And;

> *b. where there is separation between the conservatory and the dwelling, energy savings can be achieved if the conservatory is not heated. If fixed heating installations are proposed, they should have their own separate temperature and on/off controls.*

In the context of the regulations separation between a dwelling and a conservatory means:

> *a. separating walls and floors insulated to at least the same degree as semi- exposed walls and floors;*
>
> *b. separating windows and doors with the same U-value and draught stripping provisions as the exposed windows and doors elsewhere in the dwelling.*

This suggests that if the conservatory is separated from the rest of the accommodation by a wall or a door then the external fabric of the conservatory does not have to comply with the Regulations. If the conservatory is heated then there are regulations regarding the control of the system in order to avoid wastage.

This seems to be a retrograde step in terms of energy conservation since prior to 1995 it is likely that a Building Inspector would have classified any heated conservatory whether separated or not, as being within the exposed fabric of the house and therefore would have required that the external elements of the conservatory complied with the regulations on heat loss, along with the elements of the rest of the house.

Since the publication of the 1995 regulations the position regarding a conservatory built as an extension to an existing house is unclear. The Manual to the Building Regulations, 1985, [Building Regulations, (1)] exempted an extension, in the form of a conservatory, (having a transparent or translucent roof) from compliance with the Building Regulations if its floor area did not exceed $30m^2$. The 1995 edition of Part L states that, "The Manual to the Building Regulations, 1985 has been withdrawn" but to date no revision or guidance has been published. The Regulations regarding material alteration, Part L 1995 may apply in the case of a conservatory but this is not made clear.

Studies on the heating of conservatories

Prior to the publication of the 1995 edition of Part L, studies were carried out into the effect of occupant behaviour on passive solar features [Chu and Oreszczyn,1992] and [Oreszczyn, (1)&(2)1993]. The papers express Dr Oreszczyn's concern at the way in which the theoretical energy savings of glazed spaces can be reversed if building owners choose to heat the glazed space to make it comfortable, for use all year round.

The study with W L Chu surveyed the owners of ten conservatories and found that six of the conservatories were heated to the same standard as the rest of the house, two were heated intermittently and two were not heated at all. In the survey of 1,848 conservatory owners, [Oreszczyn, (1)&(2)1993] and [Moon,1991] it is estimated that 90% heated their conservatory in some way, half of this number on a regular basis. So, while insulation requirements for the

external fabric of new housing are being made more stringent, energy is being used to heat glazed spaces which have high heat loss characteristics. The 1995 edition of Part L has now covered this problem but only to a limited extent as indicated above.
The Market research report on the Marketability of Passive Solar House Designs, Final Report [London Business School, 1988] in discussing the process by which innovations in house design are diffused through the industry, notes that , "In the case of the Building Regulations, it would appear that they may encourage the diffusion of an innovation if it is both politically desirable and also directly affects the building structure, practices or materials for new buildings. In most cases however, Building Regulations have only followed after the innovation has been at least partly accepted within the industry. Hence it is, if only implicitly, those who set Building Regulations who tend to monitor the diffusion process and then only amend the rules when the market penetration has itself reached a certain level."
This statement can certainly be applied in the case of conservatories since prior to the 1995 edition, there were no specific regulations regarding conservatories built at the same time as the house and house extensions built as conservatories were exempt. Yet during the twenty or so years prior to 1995 many thousands of conservatories have been built and a proportion of these will have been heated.

Other sections of the Building Regulations which affect the design of glazed spaces in housing

Structure, Part A, with respect to structural stability
Fire safety, Part B, with respect to escape routes and internal and external fire spread
Ventilation, Part F, with respect to ventilation of habitable rooms through other rooms.
Glazing - materials and protection, Part N, with respect to the strength and positioning of glass
[Building Regulations (2)-(7)]

1.07 Prediction Methods for the Thermal Behaviour of Buildings

There are four basic methods for predicting the thermal behavior of buildings;

- Monitoring existing buildings
- Monitoring test cells
- Calculation procedures
- Computer based dynamic thermal simulation

Monitoring existing buildings

The Solar Building Study Reports, previously mentioned, highlight the problems inherent in drawing conclusions from monitored data collected in existing buildings. The information collected will depend on the location, orientation and the specific design and occupation patterns of the monitored building. In the case of a conservatory or glazed space there are many variables involved in the design such as orientation, relationship with the house, dimensions and volume enclosed, type and angle of glazing, proportions of vertical and inclined glazing, the construction of floor, dwarf walls and dividing wall(s), provision of ventilation and shading devices and the degree of overshading by vegetation and other buildings. The effect of these items need to be taken into account, individually and collectively, when interpreting monitored data.

Lifestyles also vary from household to household and even established routines can change during the monitoring period, creating problems of interpretation, [Solar Building Studies, Report no. 21]. Internal gains from people, equipment and lights offset space heating demand, but these gains depend a great deal on individual behaviour as does the opening of windows and doors. The importance of this was stressed in the report, Performance of Passive Solar Houses at Great Linford [Everet et al,1984] which described the monitoring of a group of seven similar houses in Milton Keynes, designed on passive solar principles but without sunspaces. Total delivered energy for the highest user household was 2.2 times greater than that for the lowest users.

In terms of energy savings due to the presence of a glazed space, it is difficult to determine from the reports how much of the proportion of the reduction in heating load by solar gain is due to windows and how much to the sunspace. The Copper Beech House design in particular had a great deal of glazing on the south facade including a glazed space. This space was integrated into the design of the house and was not separated from a heated, ground floor living room. Although the bedroom overlooking the conservatory benefited from solar gain this could not be passed on to the upper circulation area as the owners kept doors closed because of pets. The occupiers seem to be comfortable at lower air temperatures than other households. The degree of integration of the glazed space and the house, the large area of south facing glazing and the occupants requirements make it difficult to interpret the individual role of the conservatory in any calculation of energy savings.
[Solar Building Studies, Report no. 2]

Monitoring of test cells

Again in monitoring test cells the results obtained will depend on specific site situations. In order to test the effectiveness of a range of options for glazed space construction, shading or ventilation it would be necessary to construct numbers of test cells all in the same location, so that the options could be tested against identical weather conditions

A problem inherent in the monitoring of either test cells or existing buildings is the accuracy of the measuring instruments and their correct positioning within the monitored space.

Calculation procedures

Calculation procedures exist for estimating energy usage and solar gain in buildings. However the methods are based on assumed, steady state conditions and so cannot give an indication of the effect of changing conditions of climate and occupant behaviour.

Computer based dynamic thermal simulation

The use of computer based thermal simulation techniques allow building thermal behaviour to be analysed on the basis of changing internal and external conditions over a period of time.

In this way the heating and cooling loads and a measure of the temperatures achieved in an untreated building can be obtained over periods of changing occupant behaviour, plant utilisation and weather conditions. Additionally, the effects of different solutions for the design of the building or the use of different building materials can be compared against identical patterns of occupant behaviour, plant use and weather data. This provides a useful analytical procedure for investigating the thermal behaviour of buildings and comparing the effects of different strategies on thermal comfort and energy use.

Monitoring studies of existing houses have been extended by the use of computer based dynamic thermal simulation. [Yannas, 1994].By this method the design of the monitored building can be simulated using standardised data for climate, patterns of occupancy and internal gains. The results of the simulations then form a useful basis for comparison with other buildings or as a basis for testing the effect of other variables such as orientation, building materials or heating regime.

1.08 Conclusions from the background research and the basis for this thesis

From the limited survey of architects and from built examples it can be seen that some architects have experimented with the design of glazed spaces on the basis of providing a light, invigorating environment usable for part of the year. They have generally recognised the problems of overheating in glazed spaces and have designed in features to overcome this. Sometimes these features have been left out of the final design in order to keep the scheme within the cost budget. One architect noted that in his experience a southerly orientation is not a pre-requisite for a thermally comfortable space. Artificial heating of the conservatory or glazed space has generally not been envisaged in the architect's design. Architects do recognise the need for technical advice on the design of highly glazed areas, with regard to the control of high and low temperatures.

Some builders and developers regard conservatories as a purchase incentive, a luxury feature, and probably haven't taken on board the problems which may occur with the internal environment and the effect of high temperatures on adjoining rooms. What they have recognised is that the concept of a conservatory as an energy saving device is far too complex and unproven an issue to incorporate in their house designs and use as a marketing feature.

Sales of conservatories in the retrofit market show the enthusiastic consumer response to the enhanced lifestyle portrayed in the conservatory suppliers brochures. However, the product has not always lived up to the image, one of the problems being the thermal environment within conservatories which has not provided the promised year-round comfort. Unfortunately the proposed remedies for high and low temperatures require the expenditure of energy, which is at odds with the general movement towards the reduction of energy use in buildings. Books on conservatories aimed at homeowners also emphasise the idea of a conservatory as a room which can be used throughout the year.

The studies of the incidence of homeowners who heat their conservatory suggests that the resulting increase in energy use per household needs to be quantified, particularly with respect to conservatory orientation, type of glazing and the relationship with rest of the house, as a basis for more stringent control of conservatory design under the Building Regulations.

Historical examples indicate the possibility of reducing high temperatures in highly glazed spaces by the promotion of ventilation through openings positioned at high and low level

Academic research based on test cells, monitoring studies and thermal simulation work has mainly been based on the investigation of the domestic

glazed space as an energy saving device rather than as a thermally comfortable environment. Results from these studies did not provide conclusive evidence of energy savings.

In the light of this preliminary research, the need for an in-depth study of the design of the domestic glazed space became apparent. The main aim of this study being the investigation of the design of a highly glazed living space which would require the minimum expenditure of energy to maintain a thermally comfortable environment. Any energy savings in the space heating of adjoining rooms resulting from the presence of the glazed space could also be noted as a secondary characteristic, rather than being the primary characteristic as in previous research.

Analysis of the background reading discussed in this chapter led to the identification of the following variables which may affect the thermal comfort within a glazed space;

- orientation
- relationship with the house
- dimensions and volume enclosed
- type of glazing
- proportions of vertical and inclined glazing
- angle of inclined glazing
- floor construction
- construction of solid elements and dividing wall(s)
- provision of ventilation and shading devices
- degree of overshading by vegetation and other buildings
- geographic location
  weather conditions and time of year

It was decided that the study should concentrate on assessing the effect of these variable parameters on;

- the degree of thermal comfort provided without heating or cooling
- the amount of energy required for heating to a comfortable temperature
- reduction of the house heating load due to the presence of a glazed space
- the effect of natural ventilation in reducing high temperatures
- the effect on temperatures in rooms adjoining the glazed space

The methods which could be used for these assessments are;

- monitoring of built examples
- monitoring of test cells
- calculation procedures
- computer based thermal simulation

The use of a computer based thermal simulation program provides a means of fair comparison of the effect of a wide range of variables and combinations of variables under the same conditions of weather, occupancy and building materials data. This method was therefore selected for this investigation.

The volume private house building sector was chosen as the context for the modeling study. Interest had been expressed by some developers in the inclusion of conservatories into their standard house designs and information on the accepted sizes of houses and the construction materials used within the volume house building industry were also available.

The following chapter sets out the research and the decisions made in setting up the models for thermal simulation.
The simulation program used for the study is also described as are the strategies evolved for controlling data input and accessing and recording simulation results.
The basis for the assessment of thermal comfort in a highly glazed space is discussed and the method for the investigation of the effect of natural ventilation is described.

CHAPTER 2

The Preparation of the Thermal Models and the Thermal Simulation Strategy

2.01 Introduction

As the areas to be studied involved both the glazed space and the house, thermal models representative of current practice in both fields were needed. Results of simulations were also required for a range of situations such as the relationship of the glazed space to the house, orientation and the type of glazing to the walls and roof of the glazed space.

The following criteria were therefore defined as a basis for the modelling and simulation process;

- the glazed spaces must be of simple form so that results can be easily interpreted

- the floor area of the glazed space should be a realistic proportion of the floor area of the basic house and the proportion should be constant for all models

- the glazing materials for the glazed space should be selected from those in common usage and should provide a range of thermal insulating properties

- the basic house used should be based on housing developers standard house types

- a thermal simulation strategy was required which would limit the repetition of information input and so keep the possibilities for error to a minimum.

- building materials for the house must be in line with housing developers standards and also comply with the Building Regulations

- internal conditions must be accurate but kept as simple as possible to avoid input error

- weather data for areas of the United Kingdom where house building levels are highest should be chosen for the simulations

2.02 The Selection of House Types for Study

As discussed in Chapter 1, studies of the performance of experimental passive solar house designs including glazed spaces have generally used built examples for monitoring or as a basis for computer based thermal simulation. The design of the house has often been influenced by the specific requirements of the project such as particular site restrictions including access, orientation, gradient or the position of existing trees. The requirements of the owner of a purpose built house will also have influenced the house design. The results of monitoring or of thermal simulations in these circumstances therefore, are difficult to apply as a guide to the performance of glazed spaces either in general or in other situations.

Basic house types

For this study to have relevance to the volume house building market, the glazed spaces to be studied needed to be attached to, or be an integral part of house types based on those commonly used by housing developers. A range of basic house types were selected based on the number of bedrooms and the corresponding floor area provided [between external walls].
This information was obtained from current brochures of Housing Developers; Beazer Homes [Central] Ltd, Llewellyn Ltd, John Mowlem and Co Plc, S & S Homes and Connelly Homes, and from the brochure of the Energy World Exhibition held in Milton Keynes in 1986. [Milton Keynes Development Corporation,1986]. From this survey a typical floor area for each house type was selected.

Table 2.01 **Typical internal floor areas of developers' house types**

No of bedrooms and type of house	area range, m^2	selected area, m^2
2 bedroomed terrace house, bungalow or flat	50-61	55
2/3 bedroomed terraced or semi-detached house	67-80	75
3 bedroomed detached or semi - detached house	74-112	90
4 bedroomed detached house	92-120	110
larger 4 detached house	120-140	125

From this information the larger family homes of $90m^2$ and $110m^2$ were selected for study, as the addition of a glazed space to these houses would result in a smaller percentage increase in floor area and therefore in cost. Also the glazed space would provide useful additional living area for a family.

Taking the area for the glazed space as being 20% of the ground floor area, resulted in reasonably sized rooms, similar to those provided in standard retrofit conservatories.
In terms of assessing the thermal comfort achievable in the glazed space, the simulation results for a single storey add-on type glazed space to the 90m^2 house could be equally applicable to other house types, in particular two bedroomed houses, flats and bungalows. A proportion of houses in this latter range are bought by retired people who are at home during the day and are therefore able to make most use of the glazed space. They would also probably be prepared to pay for this additional amenity.
The larger floor area of the 110m^2 house gives greater flexibility for the arrangement of living rooms and bedrooms around an integral or semi-integral two storey glazed space, in a wide frontage type plan. Again the simulation results on thermal comfort in the glazed space could also be applicable to houses with larger floor areas than 110m^2.

Further detailed study of the developers' house types showed that the areas could be broken down further and the glazed space added as shown below;

Table 2.02 **90m^2 internal floor area**
3 bedroomed detached house: 4 people; 2 adults + 2 children

Living areas	38m^2	includes living room, dining room, kitchen
Bedroom areas	35m^2	includes bedrooms and airing cupboard
Ancillary areas	17m^2	areas of fleeting occupancy, includes circulation, bathroom
Additional Glazed space	9m^2	20% of ground floor area

Table 2.03 **110m^2 internal floor area**
4 bedroomed detached house: 5 people; 2 adults + 3 children

Living areas	42m^2	includes living room, dining room, kitchen, study
Bedroom areas	40m^2	includes bedrooms and airing cupboard
Ancillary areas	28m^2	areas of fleeting occupancy, includes circulation, bathrooms, utility room
Additional Glazed space	11m^2	20% of ground floor area

2.03 The Computer Based Thermal Simulation Program

The TAS, Thermal Analysis System, used for this study was developed originally in the Department of Applied Energy at Cranfield Institute of Technology [now Cranfield University] and is now owned by Environmental Design Solutions Ltd, [EDSL] who use the system commercially and continue to develop and distribute the software.
The system comprises of several component programs, which combine together to provide a dynamic simulation of the heat transfer processes taking place in the building under test. For the purposes of this study the 3d -Tas, A -Tas and Report Generator Programs were used.

The 3d -Tas Program
In the 3d -Tas program the building form can be entered floor by floor, graphically or by digitising from a scale drawing. Perspectives and elevations can be requested in order to check the accuracy of the resulting model. The building model is then divided into zones on the basis of occupancy, specific heating or cooling requirements, orientation etc., which need individual or collective consideration during the thermal simulation process. Building elements can be designated, according to different materials or combinations of materials, occurring in the roofs, ground and intermediate floors and internal and external walls. Windows and doors can also be sized and positioned. Floor to ceiling areas of external wall glazing or glazed roofs can be designated separately. The latitude and orientation of the model are set as required but can be changed for later comparative simulations.
Shadow calculations can then be performed on the finished 3d-model which plot the path of solar radiation incident on the building for periods up to a whole year. During the thermal simulation process, solar radiation incident on windows and glazed doors is utilised as being distributed evenly over the surfaces of the receiving room. The glazed external walls and roofs however, are designated so that the path of the direct component of the incident solar radiation can be tracked through the glazed areas, taking into account the transmission characteristics of the glazing materials, on to the surfaces of the internal receiving walls. This process gives a more accurate representation of the changing pattern and intensity of incident solar radiation over the period of the simulation and is particularly relevant to the modelling of buildings with large areas of wall and roof glazing, as required for this study.

The A-Tas Program
In the A -Tas program building constructions, made up from layers of appropriate materials, can be applied to the designated building elements. The thermal characteristics of the building constructions, such as thermal response and U-value can be viewed and checked against required values. In this way constructions can be checked for compliance with the elemental maximum U-values required by the Building Regulations. See Figure 2.01, overleaf.

Time Now	Date	Consultant	Program
14:18:05	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsews/ > 0

C-Code: bsews/1	Construction name: external wall slow response U=0.43

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.725	0.400	0.930	0.850	0.465	4.7

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/8 LIGHTWEIGHT PLASTER 8 *3	13.00	0.201	770.0	837.0	-	11.000
3	am1block/4 CLINKER CONCRETE BLOCK *1	100.00	0.350	1050.0	1057.0	-	14.800
4	am1ins/2 GLASS FIBRE 2 *3	50.00	0.035	25.0	1000.0	-	2.880
5	am1cav/4 20MM AIR (HORIZONTAL FLOW)	20.00	-	-	-	1.270	1.000
6	am1brick/4 BRICKWORK 1% m.c. *4	105.00	0.540	1600.0	750.0	-	8.000
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.430 (Wall) 0.435 (Roof) 0.419 (Internal) 0.435 (Ground Floor)

Figure 2.01 **An example of a building construction data sheet**

Internal conditions files can be set up for each of the designated zones for particular days of the week or times of the year. For instance the week could be split into weekdays and weekends to suit the pattern of occupancy of a family who are out of the house on weekdays. Similarly the year can be split into a heated Winter period and an unheated Summer period. Particularly appropriate for this study is the possibility of splitting the year into Greenwich Meantime and British Summertime as explained in the Chapter 2.07 on Zoning and Internal conditions. The internal conditions indicate the quantity of internal gains, to be taken into account during the simulations, from the rates of sensible and latent heat output from occupants, lighting and equipment and the duration of these outputs. The requirements for heating and cooling plant, set points, controls and periods of operation are also entered as are air infiltration and mechanical ventilation rates.
An example of the Internal Conditions datasheet for a living room is included overleaf, in Figure 2.02.

The Thermal Simulation Program
At this point an appropriate weatherfile can be selected from the database and a thermal simulation performed for either one day or for any period up to a year. The results from the one day simulation appear on screen in graphic or tabular form and supply hourly results for each zone in terms of internal air, mean radiant and resultant temperature. Hourly heating and cooling loads are also given for each zone. Humidities, surface temperatures and the occurrence of surface and interstitial condensation are also available.
The results from the longer batch simulations are available in tabular form and give heating and cooling loads and solar gain per zone, per month. The results of temperature checks can also be obtained. These give the number of hours and days within the simulation period when the air temperature in each zone exceeded levels, set by the operator, during certain times of day, totalled for the period of the simulation.

The Report Generator Program
The Report Generator program provides an opportunity for obtaining more detailed information from the longer simulations than can be obtained from the standard output. For instance hourly readings for the resultant temperature can be obtained, a particularly important point for this study as explained in Chapter 2.05. The use of the Report Generator involved writing computer programs specifically for this study in order to obtain the number of hours when the temperature within the glazed spaces rose above and fell below certain levels, during specified times of day and at different times of the year. The development of the programs is described in Chapter 2.06 and examples of the programs are included in Appendix C.

DATABASE OF INTERNAL CONDITIONS

Time Now	Date	Consultant	Program
14:53:22	01:Sep:95	ACADEMIC USE	A-Tas 7.96

Search Pattern: bsl/ 1

IC - Code	Internal Conditions Description
bsl/1	living areas gmt heated mon-fri

Temp. Upper Limit (deg C)	Temp. Lower Limit (deg C)	Prop'l Control (deg C)	On-off Control (deg C)	Humidity Upper Limit (%)	Humidity Lower Limit (%)	Plant Max. Outside Temp. (deg C)	Plant Off Outside Temp. (deg C)
50.0	20.0	0.0	1.0	100.0	0.0	0.0	0.0

Operating Period	Time Plant On	Time Plant Off	Heating (kW)	Cooling (kW)
1	6	9	SIZE	0.0
2	16	23	SIZE	0.0
3				
4				

	Radiant Prop.	View Coefft.
Heating	0.500	0.248
Cooling	0.000	0.000
Lights	0.800	0.509
Occupants	0.200	0.227
Equipment	0.200	0.124

Occupation Period	Occupation Duration (hrs)	Infiltr. Air (ACH)	Ventil. Air (ACH)	Lighting Gain (W/m2)	Occupancy Sensible Gain (W/m2)	Occupancy Latent Gain (W/m2)	Equipment Sensible Gain (W/m2)	Equipment Latent Gain (W/m2)
1	7	0.750	0.000	0.000	0.000	0.000	2.000	0.000
2	2	1.000	0.000	5.000	9.800	3.900	7.500	1.500
3	8	0.750	0.000	0.000	0.000	0.000	2.000	0.000
4	2	1.000	0.000	5.000	9.800	3.900	36.000	7.500
5	4	0.750	0.000	7.500	4.900	1.900	8.500	0.000
6	1	0.750	0.000	0.000	0.000	0.000	2.000	0.000
7								
8								

Figure 2.02 **An example of an internal conditions data sheet**

The Treatment of Solar Radiation in the Tas Simulation Program

Solar radiation incident on the building exterior

In the Tas simulation programme the values for direct and diffuse solar radiation on a horizontal surface, included in the weather files, provide the basic data for the calculation of the direct, diffuse and ground reflected solar radiation incident on the surfaces of the building model under test.
The calculation itself is based on Michalsky's algorithm for solar position [Michalsky, 1988(1) &(2) and 1989] and is expressed in terms of unit vectors pointing towards the sun. This approach was developed in order to manage the complexity of solar geometry and make the calculation procedures more amenable to computer programming. The Tas method is described in the excerpt from the Building Analysis (A-Tas) Theory Manual [Environmental Design Solutions Ltd] included in Appendix F.

Solar transmission and absorption - characteristics of normal incidence

The solar transmission and absorption characteristics of transparent constructions used in the Tas thermal analysis are derived in advance of simulation from the properties of its constituent layers. Each of these layers is either a Transparent Layer or a Gas Layer. Transparent Layers include either glass panes, layers of transparent insulation and blinds. Gas layers are usually air gaps but may be Argon filled cavities. For the purposes of solar radiation calculations Transparent Layers are represented by a transmittance and two reflectances, all applying at normal incidence. The two reflectances relate to radiation from the two sides of the element, to allow for glass types with special coatings and blinds with different finishes on each side. Gas layers are assumed to be totally transparent.
To calculate the characteristics of a glazing construction a normal ray is beamed into the construction from each side in turn. Reflections and absorptions are calculated and successive reflected rays are traced until residuals become small. This calculation yields an overall transmittance, and [for rays from each side] a reflectance and a distribution of absorptance through the construction, all applying at normal incidence.
Using the assumed linearity of heat transfer in the glazing construction, the absorptance distributions are then reduced to equivalent absorptances on the outside and inside surfaces. Absorptance, α_p occurring at a point within the construction having thermal resistances, $r_{p\,ext}$ and $r_{p\,int}$ to the inside and outside surfaces respectively, can be shown to be equivalent to absorptance $\alpha_{p\,ext}$ at the outside surface and $\alpha_{p\,int}$ at the inside surface, where

$$\alpha_{p\,ext} = \frac{\alpha_p\, r_{p\,int}}{(r_{p\,ext} + r_{p\,int})} \quad \text{and} \quad \alpha_{p\,int} = \frac{\alpha_p\, r_{p\,ext}}{(r_{p\,ext} + r_{p\,int})}$$

This reduction is made possible by a variant of Thevenin's theorem in electric circuit theory. It provides a complete characterisation, in terms of a small number of parameters of the construction's behaviour as it affects its environment.

The normal incidence transmittances and absorptances of a construction are calculated whenever a construction is created or edited. Absorptances are given for rays from both directions. Transmittance is always the same for the two directions, so a single value is given for this parameter.

Solar transmission and absorption - angular characteristics

Transmission and absorption characteristics of transparent constructions at non-normal incidence are calculated from the Fresnel equations [Hecht and Zajac,1974]

Figure 2.03 below shows a ray passing through a single layer of material. The transmission angle θ_t is related to the incidence angle θ by Snell's Law:

$$\sin \theta_t = \frac{(\sin \theta)}{n},$$ where n is the refractive index of the layer

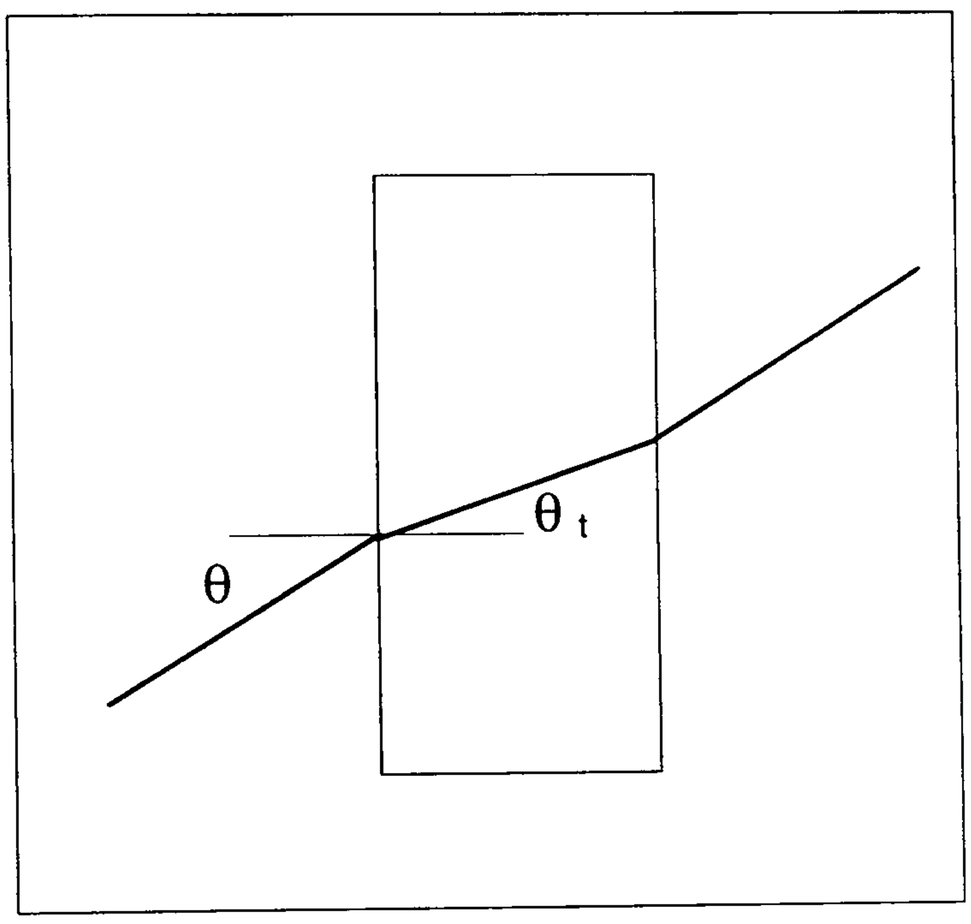


Figure 2.03 **Transmission through a single layer transparent construction**

The transmission at each of the two interfaces is given by the Fresnel Equations for polarisation perpendicular and parallel to the plane of incidence:

$$t_{perp}(\theta) = \frac{4\, n\, c(\theta)}{(1+ n\, c(\theta))^2} \quad \text{and} \quad t_{para}(\theta) = \frac{4\, n\, c(\theta)}{(n + c(\theta))^2}$$

where, $c(\theta) = \frac{\cos \theta_t}{\cos \theta}$ and $\cos \theta_t = \sqrt{(1 - (\sin^2 \theta)\, n^{-2})}$.

from Snell's Law

Owing to a lack of detailed refractive index data for all layers, the Fresnel equations are applied not to the glazing construction itself but to an approximately equivalent single layer construction.

Two alternative strategies are possible for achieving an approximate match between the single layer construction and the actual construction. Both are based on matching the normal transmittance and absorptance. These procedures produce accurate angular characteristics for the most common glazing systems and acceptable angular characteristics in most cases.

Opaque building components

Opaque building components are assumed to have isotropic solar absorptance characteristics: the absorptance is assumed to be equal at all angles.

Solar transmission and absorption calculations

During simulation, solar radiation entering the building through windows and other transparent building components is distributed over the building surfaces as described later in the section on 'Solar distribution inside the building'. In the distribution process, the radiation absorbed by the surfaces of each zone is totalled and stored in the quantities $q_{\text{i sol int}}$ and $q_{\text{i sol ext}}$ where

$q_{\text{i sol int}}$ is the solar radiation [Watts] absorbed on the internal surface of the zone

$q_{\text{i sol ext}}$ is the solar radiation [Watts] absorbed on the external surface of the zone

In the case of transparent components the 'internal' and 'external' labels on these quantities refer to the effective absorption on the two surfaces.

In the case of the external surfaces of opaque building components which are exposed to the external environment, $q_{\text{i}}^{\text{sol ext}}$ is given by the expression:

$$q_{\text{i sol ext}} = \alpha_{\text{i ext}} \left(I_{\text{i dir}} + I_{\text{i sky}} + I_{\text{i gnd}} \right)$$

where

α_{iext} is the external solar absorptance of the component

$I_{\text{i dir}}$ is the direct solar radiation [Watts] incident on a surface

$I_{\text{i sky}}$ is the diffuse solar radiation [Watts] incident on a surface from the sky

$I_{\text{i gnd}}$ is the incident ground reflected solar radiation [Watts] incident on a surface

For an exposed transparent component $q_{\text{i sol ext}}$ will have a contribution of the same form, but it will also have a contribution from radiation returning from the zone through the component.

Solar distribution inside the building

Once it has arrived in the zone, solar radiation is distributed over the zone's internal surfaces. Some of this radiation may be transmitted back out of the building through windows, and some may be transmitted through further transparent constructions to other zones.

Solar radiation distribution algorithm

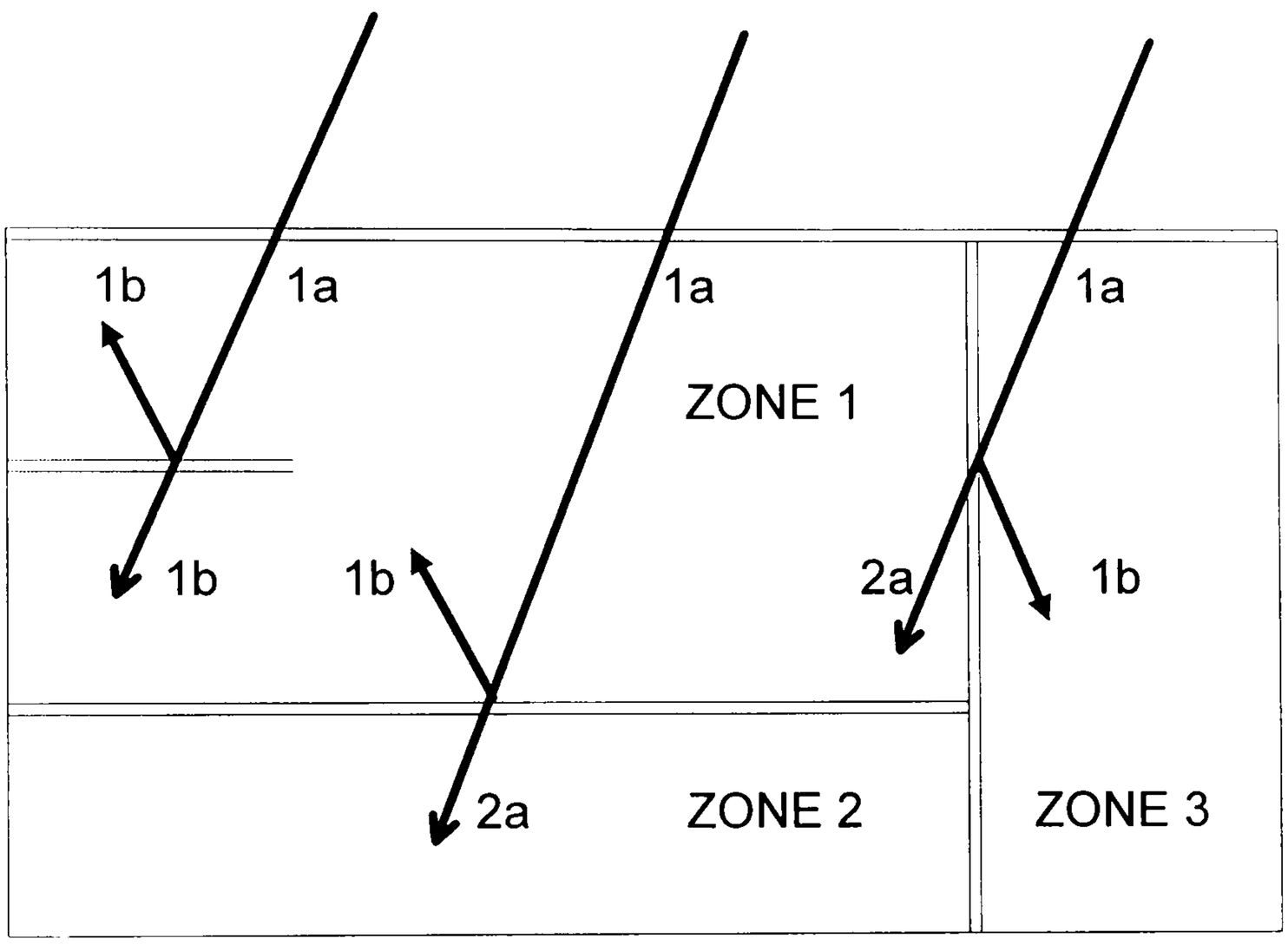
The final destination of solar radiation entering the building through transparent surfaces is determined in a series of radiation distributions. Each distribution is

Solar radiation distribution algorithm

The final destination of solar radiation entering the building through transparent surfaces is determined in a series of radiation distributions. Each distribution is carried out in turn for each of the building's zones. Its purpose is to distribute the admitted radiation among the zone's surfaces by modelling the repeated bouncing of radiation around the zone. If in the process, radiation falls on a transparent surface, transmission occurs. Radiation transmitted in this way to other zones is dealt with in the next distribution.

Figures 2.04 below and 2.05 overleaf illustrate the distribution of direct and diffuse radiation entering a building containing three zones.

Distribution of direct radiation



direct radiation

transparent walls

1 = primary distribution

2 = secondary distribution etc.

a = admitted radiation - radiation entering the space through a transparent element.

b = once-scattered radiation - radiation which has undergone one encounter [reflection or transmission] with a zone surface in the current distribution.

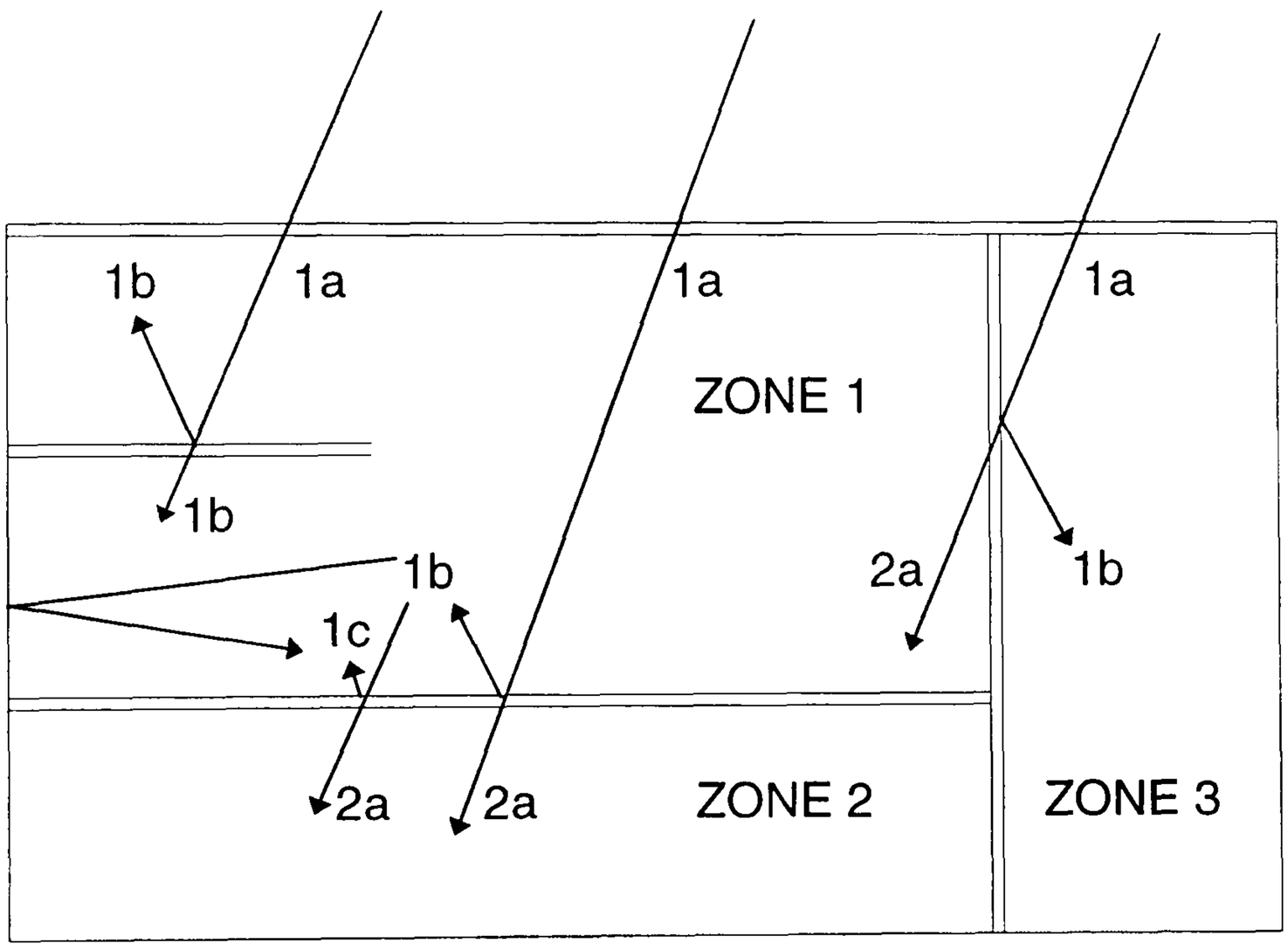
Figure 2.04 **Distribution of direct radiation**

Primary direct radiation

A facility exists within 3d-Tas for designating certain external surfaces 'tracking'. For such surfaces the direct component of solar radiation is beamed into the

building and tracked geometrically onto other surfaces of the zone at each hour. The data describing this tracking process is stored in shading files. Direct radiation admitted into the building [1] is thus in general composed of tracked and non-tracked components. Tracked direct radiation is distributed over the internal zone surfaces according to the data in the shading file. Non-tracked primary direct radiation is distributed amongst surfaces facing the sun in proportion to their projected area in the beam direction.
At each receiving surface the direct radiation is absorbed, reflected and in some cases transmitted, in accordance with the properties of the receiving surface. The reflected radiation becomes once-scattered primary radiation [1b]. Any transmitted radiation which remains in the building becomes a source of secondary radiation [2] in the appropriate zone. Any direct radiation transmitted back out of the building plays no further part in the analysis.

Distribution of diffuse radiation



diffuse radiation

transparent walls

1 = primary distribution
2 = secondary distribution etc.
a = admitted radiation - radiation entering the space through a transparent element.
b = once-scattered radiation - radiation which has undergone one encounter [reflection or transmission] with a zone surface in the current distribution.
c = residual radiation - radiation which has undergone two encounters with zone surfaces in the current distribution.

Figure 2.05 **Distribution of diffuse radiation**

Primary diffuse radiation is distributed in three stages:

1a - Admitted primary diffuse radiation. Sky and ground-scattered portions of the admitted primary diffuse radiation are treated separately. For each admitting surface, the sky radiation is distributed over the zone's surface in accordance with estimated shape factors from the surface to the sky as seen through the window. The ground radiation is distributed in an analogous way.

1b - Once-scattered primary radiation. This radiation, which consists of primary direct and diffuse radiation, plus primary diffuse radiation which has been transmitted through internal zone partitions, is distributed over the zone's surfaces on the basis of the area -based shape factors. These are such that radiation emanating from a particular surface is distributed over all the other surfaces in the zone- the source surface being excluded from the distribution. Absorption, reflection and transmission occurs at each receiving surface, with the reflected portions being collected in the residual primary radiation pool [1c]

1c - Residual primary radiation. The residual pool of radiation is distributed according to an [area x 'acceptance'] weighting where

'acceptance' = 1 - reflectance

This produces the same distribution as an infinite number of distributions on a simple area-weighted basis.

Secondary distribution of solar radiation
If any radiation has been transmitted through inter-zone partitions in the primary distribution, a secondary distribution is carried out. This follows exactly the same pattern as the primary distribution, with the exception that there is no tracked radiation.

Tertiary [etc] distribution of solar radiation
The number of distributions is currently set to eight. These all follow the same pattern except the last, where to ensure energy conservation, inter -zone transmission is returned to the source zone.

Surface solar gain and zone solar gain
The surface solar gain [$q_{\text{i sol int}}$, $q_{\text{i sol ext}}$] calculated by Tas for an internal or external zone surface is the total solar radiation [kW] absorbed by the surface in the solar distributions described above.

In the case of a transparent construction, radiation is actually absorbed within the construction, rather than at its surfaces, and in this case the surface solar gains are calculated on the basis of the equivalent surface absorptances discussed previously in 'solar transmission and absorption'.

Zone solar gain is the sum of the surface solar gains for all the surfaces facing into the zone.

Use of computer based thermal simulation methods
When using these methods the following points need to be born in mind:

- The accuracy of input data
- Minimisation of operator error
- The reliability of weather data
- The ability of the simulation program algorithms to deal with the heat transfer mechanisms accurately

In terms of the accuracy of input data, and minimisation of operator error these two items are discussed in the relevant sections dealing with setting up the model, internal conditions and building elements.

The weather data base supplied with the Tas system contains weatherfiles for locations throughout the United Kingdom, compiled by the Climate Research Department of the University of East Anglia. These files contain actual weather data for one specific year, chosen as being typical of the particular region, from monitored data collected over several years. Specific elements of the data such as temperature or solar radiation may have been collected in different parts of the region.

The accuracy of the predictions made by thermal simulation programs has been under discussion for the last few years. In the case of the Tas software, Environmental Design Solutions Ltd [EDSL] develop and supply the Tas system and also use it on a commercial basis, as consultants in the building design process.

Tas software [version 7.54] was included in the International Energy Agency [IEA] study on the Empirical Validation of Thermal Building Simulation Programmes. [Lomas et al,1994] In this study monitored data from test cells was compared with computer predictions from twenty-five thermal analysis programs, modelling the test cells under the monitored weather data conditions. The three test cells were constructed with different south facing facades; double glazed, single glazed and opaque. They were monitored for an unheated [free-floating] period in May and a period in October when the cells were heated to a set point of 30°C during the daytime.
Extracts from the tables of results included in volume 1 of the study report [Lomas et al, 1994] are set out in Table 2.04 at the end of this section. The results of the study indicate that the Tas software, as tested, tended to under-predict both zone air temperature and energy usage for space heating.
In Appendix F3 of the validation study EDSL identified the under-prediction of air temperature as being due to low estimates of downward long-wave flux generated by the Tas version 7.54 sky radiation model. They state that since the release of this version, they have reviewed the literature on sky radiation and improved the Tas algorithm accordingly. The Tas version 7.64 [1992] incorporated this improvement and was used for the first set of thermal

simulation models in this thesis. The Tas version 7.96 [1994] which included further refinements was used for the second set of thermal simulation models.

In terms of space heating, the Tas predicted figure was 94% of the monitored figure for both the double glazed and opaque cells. The predicted figures fell well within the uncertainty bands for both situations. The uncertainty bands included among other criteria an allowance for the fact that monitored relative humidity data was not available for the heated October period. Tas uses relative humidity values in the calculation of long-wave radiation to the sky and so relative humidity data collected by the Meteorological Office at a site several miles away from the test cells was used for the thermal simulations.
There was no monitored data for the heated period for the single glazed cell.

Table 2.04 **Data extracted from the study 'Empirical Validation of Thermal Simulation Programmes, Volume 1** [Lomas et al, 1994]

	Heated October Period [no monitored data for the single glazed cell]					
	Double glazed			Opaque		
	Energy MJ	Maximum air temp °C	Minimum air temp °C	Energy MJ	Maximum air temp °C	Minimum air temp °C
Tas prediction	**83.3*** MJ	**36.5***	**10.8**	**109.4*** MJ	**30.0***	**12.9**
measured	89.3 MJ	37.8	11.9	117.1 MJ	29.8	14.6
average of 25 models	74.6 MJ	38	11.6	102.4 MJ	30.0	13.1
upper uncertainty band limit	92.7 MJ	40.5	13.9	122.3 MJ	30.2	16.4
lower uncertainty band limit	78.1 MJ	36.5	11.5	105.3 MJ	29.4	14.0

*falls within or on limit of uncertainty band

	Free-floating May Period					
	Double glazed		Single Glazed		Opaque	
	Maximum air temp °C	Minimum air temp °C	Maximum air temp °C	Minimum air temp °C	Maximum air temp °C	Minimum air temp °C
Tas prediction	**28.5**	**11.6***	**30.4**	**11.0**	**16.1***	**8.3**
measured	31.0	12.2	32.6	12.1	16.8	9.2
average of 25 models	29.6	12.2	30.1	10.8	16.6	9.1
upper uncertainty band limit	33.4	13.6	35	13.6	17.5	10.0
lower uncertainty band limit	29.6	11.6	31.2	11.6	15.7	8.6

*falls within or on limit of uncertainty band

South facing solar irradiances, MJ		
	October	May
Tas prediction	**72.5**	**79.6***
measured	81.1	82.8
average of 25 models	76.2	79.9
upper uncertainty band limit	85.5	88.8
lower uncertainty band limit	76.7	76.8

*falls within or on limit of uncertainty band

2.04 The Thermal Simulation Strategy

As the purpose of the study was to compare the effect on comfort levels and heating load, of variables such as glazing type and orientation, on the same house model with and without a glazed space, it was necessary to work out a thermal simulation strategy so that the repetition of information input and the possibilities for error were kept to a minimum.

The strategy is shown in diagram form in Figures 2.03 and 2.04 and described below.

Firstly the three dimensional model of the house with glazed space was set up and checked for accuracy, using the three dimensional displays, summary files and surface description facilities.
Internal conditions and building constructions, were then added as described in Chapters 2.07 and 2.08.
The internal conditions were added for an unheated glazed space, and building constructions were added for the first of three glazing options, for the glazed space.
The model was copied to the four orientations, north, east, south and west and shadow calculations completed for each of the four resulting models.

The models were then copied twice and the second and third glazing options added, resulting in a total of twelve models. Simulation results were obtained for the house with unheated glazed space for;

- the number of hours of comfortable temperatures in the glazed space
- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in living rooms and bedrooms.

The internal conditions were then changed on all twelve models, to include a heated glazed space. Simulation results were obtained for the house with the heated glazed space for;

- the monthly space heating load for the house
- the monthly space heating load for the glazed space

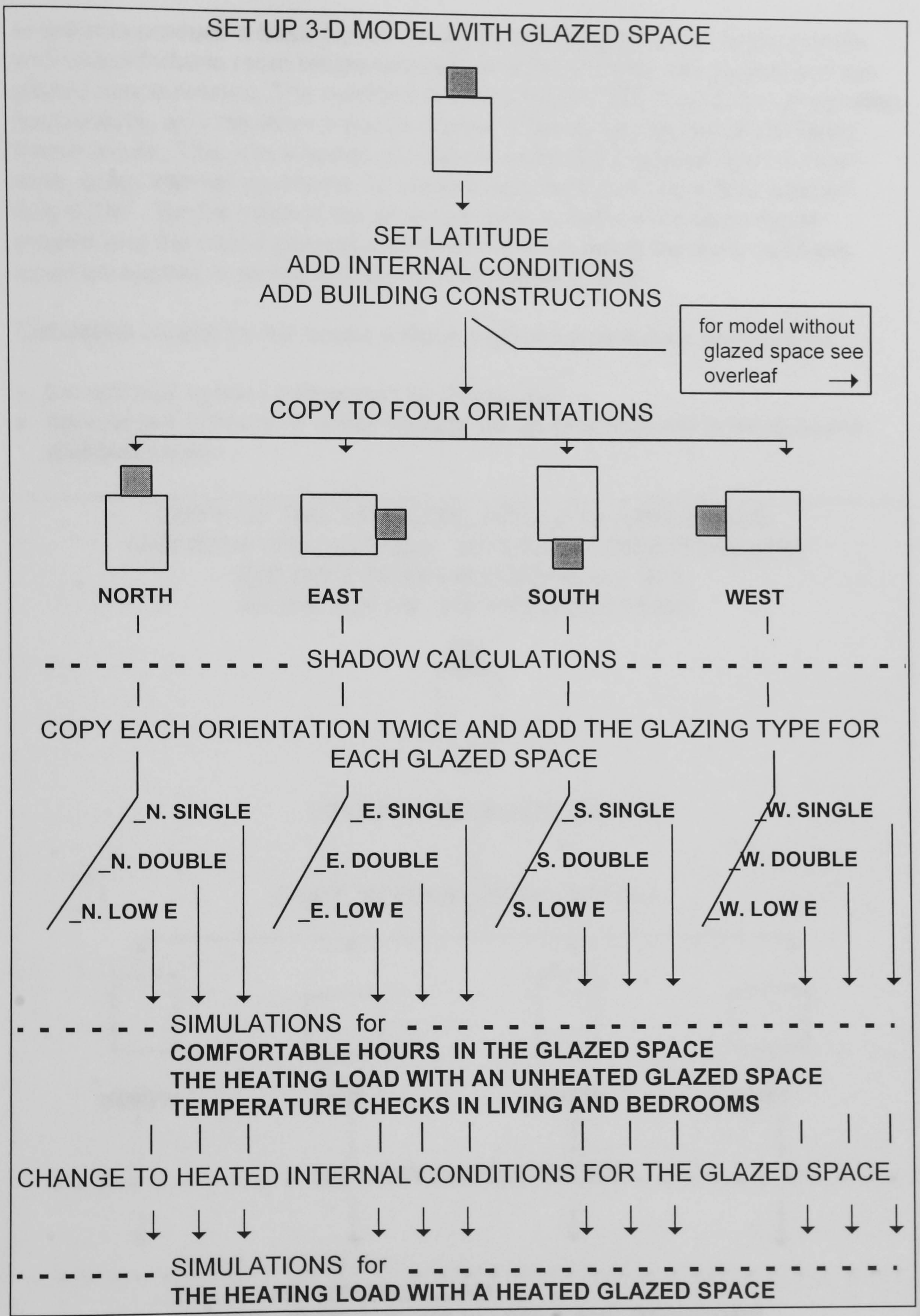


Figure 2.06 **The simulation strategy for the house model with glazed space**

In order to produce a basic house model for the comparison of heating loads and uncomfortable room temperatures one of the models was copied and the glazed space deleted. The numbers for the zones in Tas have to be designated sequentially, and therefore a nominal zone 1 had to be retained in the basic house model. This was situated on internal walls of the ground floor ancillary area, given internal conditions for the ancillary area and had a floor area of only $0.1m^2$. By this method the zone numbers remained the same for all models and the report generator programs incorporating the zone numbers could be applied to all the models without further editing.

Simulation results for the house without a glazed space were obtained for:

- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in living rooms and bedrooms

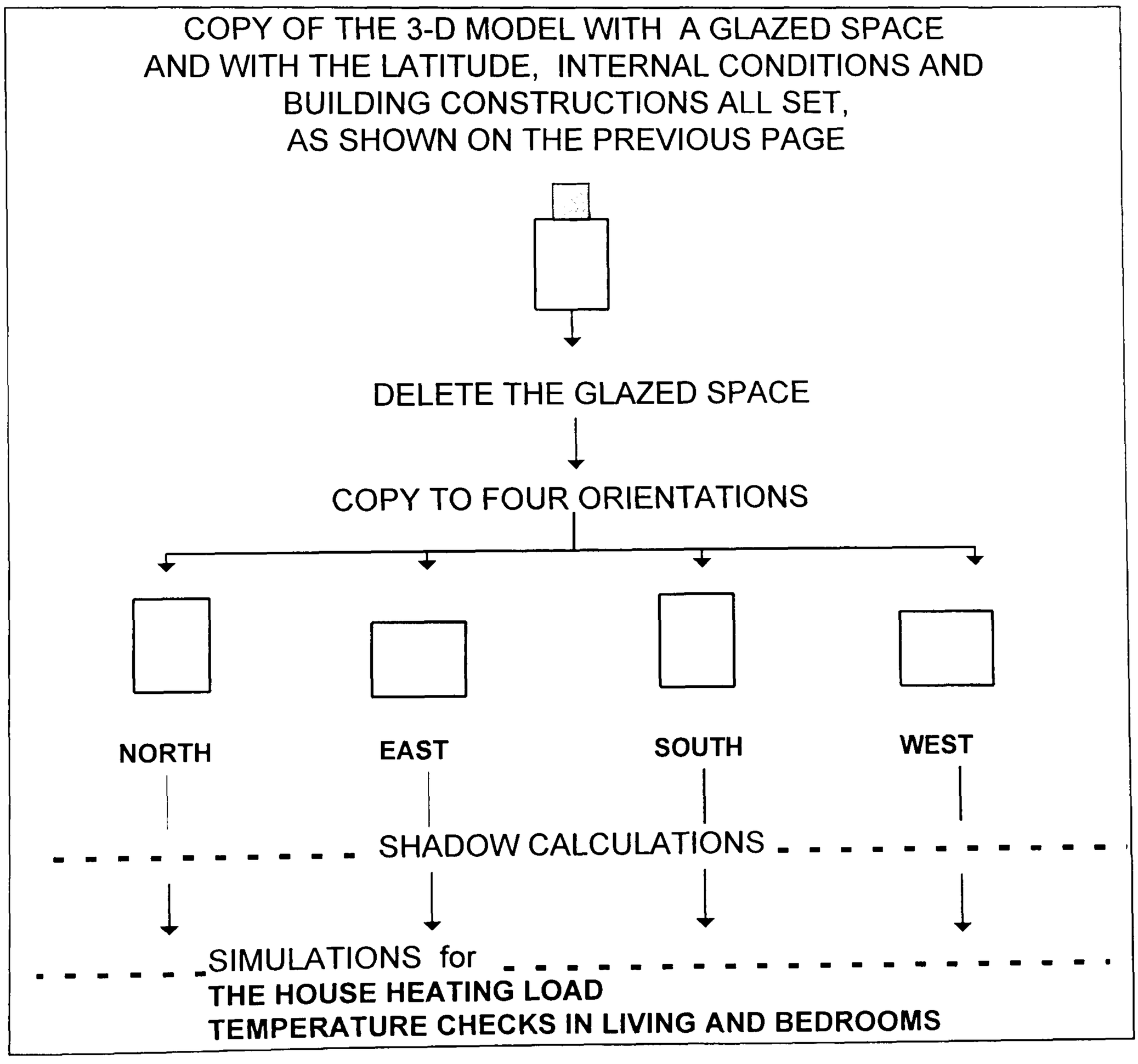


Figure 2.07 **The simulation strategy for the basic house model**

Infiltration rates
Infiltration rates for the initial simulations were set at levels, as shown in the internal conditions data sheets, consistent with house and conservatory building construction and with closed windows, Chapter 2.07. The results of the first thermal simulations therefore provided a datum against which later simulations incorporating higher infiltration rates to represent open windows or ventilators could be compared.

Heating loads
The heating load results, obtained from the thermal simulations, provide only a basis for the comparison of the different models. As indicated on the internal conditions datasheets, the size of the heating plant is not defined and the set-point temperature for each zone is achieved by the end of the first hour of operation. The temperature in each zone is maintained at the set-point throughout the rest of the operating period, rather than fluctuating within a control band. Frost protection has not been included in the heating plant requirements. It was considered that this approach of assessing the heating load, on the basis of maintaining a constant temperature within set operating periods, would provide an adequate basis for the comparison of space heating loads required for this study.

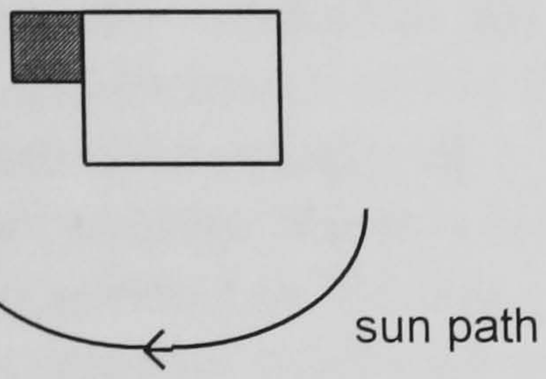
Inter-zonal air movement
No attempt was made to transfer warm air from the glazed space into the house in order to reduce the house heating load. Inter-zonal air movement could have been used in order to transfer air at certain times of day but the Tas program does not supply a temperature control mechanism which would trigger the operation of this transfer at certain temperatures. Any reduction in the house heating load due to the presence of the glazed space was therefore due to the additional insulating effect provide by the fabric of the conservatory and by the elevation of the glazed space air temperature above external air temperature.

Strategy decisions
The following decisions were made during the course of developing and simulating the first set of thermal models;

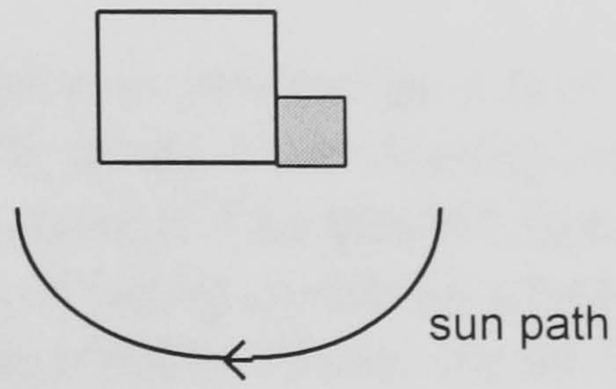
- the glazed space should be symmetrically placed on the face of the house to maintain the same overshading possibilities for all orientations, further explanation below
- resultant temperature was a better indicator of thermal comfort in the glazed space than air temperature, necessitating the use of the Report Generator facility rather than the standard simulation output
- results in the form of hours of comfortable temperatures on a yearly basis were not adequate for the guidelines envisaged
- the comfortable hours in the glazed space should be expressed in terms of the time of day, per month
- an indication of the cause of discomfort in the glazed space was needed, such as whether the temperature was too hot or too cold.

Positioning of the glazed spaces

Initially the glazed space was positioned asymmetrically on the face of the house. After further consideration it was realised that this would also result in an asymmetrical shading pattern on the glazed space by the house, for each orientation. This is illustrated below for the west and east orientations.



west orientation
south face of glazed space
overshadowed



east orientation
south face of glazed space
not overshadowed

The model was therefore revised and the glazed space positioned centrally on the facade.

2.05 Thermal Comfort

The human body's sensation of thermal comfort within a given space depends on the air temperature, radiant temperature, air movement and humidity of the space, together with the individual's clothing and level of activity.

Thermal comfort in the glazed space

For the purpose of this thesis a glazed space is defined as a domestic multi-use space and occupants could be expected to adapt their clothing levels to improve their thermal comfort to a certain extent. The glazed space could also be regarded as having the visual benefits of being outdoors when ambient air temperature would be too cold for thermal comfort. Under these circumstances occupants would therefore possibly tolerate lower temperatures than in an enclosed room. Occupants could also be expected to cope with higher temperatures in a glazed space than in a work situation, if their activity level was low. A fairly wide range of temperatures could therefore be acceptable for the glazed space.

The CIBSE Guide gives 16°C as a minimum air temperature which should be provided for people engaged in light work and 27°C is given as the air temperature above which people will begin to feel uncomfortably hot. [CIBSE, 1986, A1].

Other sources define varying comfort ranges specifically for a glazed space as 'an acceptable air temperature range of 15°C - 27°C' [Yannas,1994, p111] and 'an air temperature comfort range of 18°C - 25°C' [Baleynaud,1991].

In the Msc Thesis, [Swann,1991] the comfortable range was defined as air temperatures between 16 °C and 25°C.

However in a highly glazed space other temperatures affect occupant comfort. In addition to air temperature, the occupants will also sense the effect of the solar radiation passing directly through the glazing, which can lead to discomfort. The occupants will also be affected by radiation reflected from the surfaces within the space or absorbed by the surfaces and re-emitted into the space. During periods of cold weather the glazing will radiate heat to the colder external environment and occupants will sense heat being radiated from their bodies to the colder glazing, though they may interpret this situation in terms of feeling the coldness coming from the glazing. Some assessment of the effect of internal surface temperatures on the occupants is therefore needed to give a more accurate assessment of thermal comfort in a glazed space.

As discussed previously, standard output from Tas simulations gives the number of hours or days when the air temperature in each zone exceeds or falls below specified values during specified hours. One day simulations give hourly readings for air, mean radiant and resultant temperature over the specified day. The report generator provides the opportunity for processing the hourly readings of these three temperatures, for simulations longer than one day.

The mean radiant temperature, in the Tas program is a measure of an occupant's perception of the radiant temperature in the zone, calculated as the weighted average of the zone's surface temperatures, modified by the effects of gains [plant, incidental gains and the diffuse component of solar gain]. The resultant temperature, in the Tas program, is the average of air temperature and mean radiant temperature and is a measure of the temperature perceived by occupants.

Preliminary one day simulations on a single storey glazed space attached to a $90m^2$ house, [First thermal model] amply show the effect of the mean radiant temperature on the internal environment. If the comfortable air temperature range is taken as 16^oC - 27^oC , then the following observations can be made from extracts taken from the results of one day simulations shown in Table 2.05;

- on day 76 all the hourly air temperatures shown were below 16^oC and therefore those hours would not have counted as comfortable hours. However the effect of solar radiation and the higher temperatures of the surfaces, as shown by the mean radiant temperature, gives a resultant temperature above 16^oC, indicating that the occupants could have been comfortable during these periods.
- on day 150 air temperatures for the hours shown were below 27^oC and therefore the hours would be classified as being comfortable. However the effect of solar radiation and the surface temperatures has again increased the mean radiant temperature, bringing the resultant temperature above 27^oC.

Table 2.05 **Comparison of air, mean radiant and resultant temperatures**

simulation day	hour	air temperature ^oC	mean radiant temperature ^oC	resultant temperature ^oC
day76 : March 17th	12.00	13.90	19.04	16.47
	13.00	14.87	19.64	17.25
	14.00	15.30	19.27	17.28
	15.00	14.85	18.30	16.58
day 150 : May 30th	11.00	23.96	30.87	27.41
	12.00	25.19	32.56	28.88
	16.00	25.77	30.81	28.29
	17.00	25.96	30.63	28.29

This indicated that in a glazed space, air temperature was not a reliable indicator of comfortable temperature and the resultant temperature should be used as the basis for assessing the number of comfortable hours.

The comfortable range on which the models were to be assessed was therefore defined as a minimum resultant temperature of 16°C and a maximum resultant temperature of 27°C.

Humidity levels in the glazed space have not been investigated in this study since the spaces are envisaged as living rooms rather than plant growing environments. In this case humidity levels could be expected to be similar to those in the other living rooms in the house, if care is taken to separate the glazed space from moisture vapour producing areas. It could also be assumed that in new-build housing, methods of dealing with moisture vapour would be installed in bathrooms and kitchens in accordance with the requirements of the Building Regulations. [Building Regulations (4) 1995].
Air movement was included in the initial simulations, in terms of a basic infiltration rate as shown in Chapter 2.07 on Internal Conditions. The effect of increasing the air change rate was investigated in later simulations

Overheating in the adjoining rooms
In several of the houses monitored for the Solar Building Studies high temperatures were recorded, particularly in the bedrooms. [Solar Building Studies, 16 and 21]. This thesis is therefore also concerned with the effect of high temperatures in the glazed space on the air temperatures in adjoining rooms. The numbers of hours when the air temperature rose above 27°C in the living rooms and above 25°C in the bedrooms were extracted from the simulation results, via the report generator programs.

2.06 The Development of the Report Generator Programs

Standard output from the A-Tas simulations gives the results of temperature checks for air temperature in terms of the number of hours in the year and per zone when the air temperature exceeds or falls below set temperatures, within certain times of the day, for up to a total of six situations as requested by the operator.
The use of the Report Generator allows post-processing of the total range of data from the simulation results. In order to access this output, programs have to be written by the operator specifically for the project.
Initially, this facility was used in order to obtain the number of hours when the resultant temperature was greater than 16°C but less than 27°C, from 7.00 - 23.00hrs during the British Summertime and Greenwich Meantime periods.
More detailed programs were then written in order to obtain the number of such hours occurring during individual months and for separate times of day; morning, 8.00 -13.00hrs, afternoon, 13.00 -18.00hrs and evening, 18.00-23.00hrs.
These programs were developed further in order to obtain the number of hours when the resultant temperature fell below 12 °C or exceeded 30 °C in the glazed spaces during individual months and the times mentioned above.
Using these programs a far more detailed picture of the number of comfortable hours occurring in the glazed spaces, based on resultant temperature rather than air temperature, could be obtained.
Similar programs were written in order to obtain air temperature checks for living rooms, hours above 27°C between 6.00 - 23.00hrs and bedrooms, hours above 25°C between 22.00 - 8.00hrs.

Examples of the programs are included in Appendix C.

2.07 Zoning and Internal Conditions

As the computer models were set up in order to investigate the effect of heating a glazed space on the house heating load as well as estimating the hours of comfortable temperatures within glazed spaces, it was necessary to set up internal conditions data for the house which conformed as closely as possible to recorded heating patterns and occupant behaviour. The following paragraphs describe how the internal conditions were devised from a number of sources.

Zoning the accommodation
The A -Tas programme requires that the building under test is divided into zones. Each zone identifies a room or rooms for which a set of Internal Conditions consisting of occupancy, artificial lighting and equipment use patterns together with heating, cooling or ventilating regimes can be set up and simulation results identified. For the purpose of this study separate zones were designated as follows;

- Zone 1 : Glazed space
- Zone 2 : Living areas, including living room, study, dining room and kitchen.
- Zone 3 : Ancillary spaces, including circulation areas, bathrooms, utility room
- Zone 4 : Bedrooms, including the airing cupboard
- Zone 5 : House roofspace

corresponding to the areas identified in Tables 2.02 and 2.03.

Internal conditions
The following internal conditions data were required for typical 24 hour periods for each zone:

- Occupancy pattern
- Incidental gains [sensible and latent] from occupants, lights and equipment
- Ambient air infiltration rates
- Heating schedules
- Heating set points

To avoid over complication and therefore reduce the possibilities for error when entering the data, internal conditions were developed which could be used throughout the study, for the same zone designations in houses of different gross areas. Incidental gains are entered in Watts/m^2 and it is therefore assumed in this approach that the larger the house the greater the number of occupants and the greater the amount of cooking, lighting and electrical equipment. Analysis of developers' house plans showed that the floor areas of living rooms [zone 2] and bedrooms [zone 4] tended to increase proportionally with increases in total floor area. Rooms of varying size such as bathrooms, utility rooms and circulation areas, all of which also have short occupancy duration, were therefore grouped together as one zone [zone 3].

Patterns of occupancy
Internal conditions for the house: living rooms and bedrooms, were set for weekdays, with intermittent occupancy and heating schedules, and weekends, with all-day occupancy and heating.

Greenwich Meantime and British Summertime
The Tas simulations and weather data for the United Kingdom are based on Greenwich Meantime. In order to achieve accurate thermal simulations and taking into account the high level of thermal response of a glazed space to the presence of solar radiation, internal conditions were set up for occupation periods based on the Greenwich Meantime equivalent of British Summertime, in addition to the basic conditions set up on Greenwich Mean Time. For example, an activity starting at 7.00hrs for the whole of the year would be entered as starting at 6.00hrs for the British Summertime period. The A-Tas simulation programme is able to substitute this different set of internal conditions for each zone at the appropriate time in the simulation period.

Internal conditions datasheets
The internal conditions datasheets drawn up for each zone are included and discussed on the following pages.
The sources of the information used in compiling the datasheets are included in Appendix D

Table 2.05 **Summary of the codes used to identify the internal conditions datasheets**

	Greenwich Mean Time		British Summertime	
Accommodation	Weekday	Weekend	Weekday	Weekend
Glazed space - unheated	bsgsun/1	bsgsun/1	bsgsun/1	bsgsun/1
Glazed space - heated	bsgs/1	bsgs/2	bsgs/3	bsgs/4
Living areas	bsl/1	bsl/2	bsl/3	bsl/4
Bedrooms	bsb/1	bsb/2	bsb/3	bsb/4
Ancillary areas	bsa/1	bsa/1	bsa/1	bsa/1

Table 2.06 **Radiant properties of plant and gains which apply to all the internal conditions datasheets**

	Radiant proportion	View coefficient
Heating	0.5 (single col. rad.)	0.248
Cooling	0.0	0.0
Lights	0.8 (tungsten)	0.509 (ceiling fitting)
Occupants	0.2	0.227
Equipment	0.1	0.124 (perim.of room)

- **Zone 1: Glazed space**

The unheated glazed space has no occupancy, lighting or equipment gains as this space would only be used if the temperature was comfortable. Entering figures for these items when the temperature would actually be too hot or too cold for occupation could distort the results of temperature checks.
There is a constant ambient air infiltration rate over the 24 hour period of 0.85 ac/h which has been taken from the Passys report [Baker et al,1991] on the monitoring of a test cell with conservatory.
The only information entered on the datasheet is as shown below;

Internal Conditions Datasheet Code: bsgsun/1 Zone 1
Location: unheated glazed space / weekday and weekends / GMT and BST

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	24	0.85	-	-	-	-	-	-

In the heated glazed space lighting gains are added in the evenings during the Greenwich Meantime Period.
Occupancy gains have again been omitted as the occupancy is difficult to predict and the heat losses and gains through the glazed envelope would be of a much greater order to that of gains from occupants.
The infiltration rate is again taken as 0.85ac/h.
Heating is included to a set point of 20°C for five hours on weekday evenings and all day and evenings at weekends.

The internal conditions datasheets for the heated glazed space follow on the next two pages.

Internal Conditions Datasheet Code: bsgs/1 Zone 1
Location: Heated glazed space / weekday / GMT

Temp. upper limit °C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
70.0	20.0	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	16.00	21.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	17	0.85	-	-	-	-	-	-
2	4	0.85	-	10.0	-	-	-	-
3	3	0.85	-	-	-	-	-	-

Variation for BST Code: bsgs/3

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	15.00	20.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	24	0.85	-	-	-	-	-	-

Note: The “Time plant on” entry reflects the one hour period needed to bring the temperature up to the set point.

Internal Conditions Datasheet Code: bsgs/2 Zone 1

Location: Heated glazed space / weekend / GMT

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
70.0	20.0	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	8.00	21.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	17	0.85	-	-	-	-	-	-
2	4	0.85	-	10	-	-	-	-
3	3	0.85	-	-	-	-	-	-

Variation for BST Code: bsgs/4

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	7.00	20.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	24	0.85	-	-	-	-	-	-

- **Zone 2 : Living rooms**

The sitting room, dining room, kitchen and study are combined in this zone to allow for combinations of these rooms such as kitchen/diner or lounge/diner which occur in many house plans. Connecting doors are likely to remain open when the rooms are in use and the occupants will probably be spread among these areas during the evenings and the weekends. Incidental gains are included for televisions and other electrical equipment and for cooking, refrigerators and freezers, clothes washing and drying.
The background infiltration is increased in this zone in the early morning and early evening to represent occupants leaving and returning.
A large rise in equipment gains occurs in the early evening due to cooking and the use of electrical equipment such as a television. The cooking load is reduced for the Britsh Summertime period.
The heating plant is made available throughout the year as this probably coincides with the domestic heating practice of turning the heating on in summer when the living room temperature falls below a comfortable level, generally in the evenings.
The Tas programme brings the zone temperature up to the set point temperature during the first hour of operation. Therefore the “Time plant on” entry in the datasheets is one earlier than the time when the set-point temperature is required.
No control bands or frost protection were specified for any of the zones.

The internal conditions datasheets for the Living rooms are shown on the following pages.
The sources for the internal gains data; occupancy data, infiltration, heating schedules and set points are included in Appendix D.

Internal Conditions Datasheet Code: bsl/1 Zone 2
Location: Living rooms / weekday / GMT

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	20	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.00	9.00	size	-
2	16.00	23.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	7	0.75	-	-	-	-	2.0	-
2	2	1.0	-	5.0	9.8	3.9	7.5	1.5
3	8	0.75	-	-	-	-	2.0	-
4	2	1.0	-	5.0	9.8	3.9	36.0	7.5
5	4	0.75	-	7.5	4.9	1.9	8.5	-
6	1	0.75	-	-	-	-	2.0	-

Variation for BST Code: bsl/3

1	5.00	8.00	size	-
2	15.00	22.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	6	0.75	-	-	-	-	2.0	-
2	2	1.0	-	-	9.8	3.9	7.5	1.5
3	8	0.75	-	-	-	-	2.0	-
4	2	1.0	-	-	9.8	3.9	12.0	2.5
5	4	0.75	-	5.0	4.9	1.9	8.5	-
6	2	0.75	-	-	-	-	2.0	-

Internal Conditions Datasheet Code: bsl/2 Zone 2

Location : Living rooms / weekends / GMT

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	20	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.00	23.00		

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	7	0.75	-	-	-	-	2.0	-
2	2	1.0	-	5.0	4.9	1.9	7.5	1.5
3	8	1.0	-	2.5	4.9	1.9	7.5	1.5
4	2	1.0	-	5.0	9.8	3.9	36.0	7.5
5	4	0.75	-	7.5	4.9	1.9	6.0	-
6	1	0.75	-	-	-	-	2.0	-

Variation for BST Code: bsl/4

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	5.00	22.00	size	-

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	6	0.75	-	-	-	-	2.0	-
2	2	1.0	-	-	4.9	1.9	7.5	1.5
3	8	1.0	-	-	4.9	1.9	7.5	1.5
4	2	1.0	-	-	9.8	3.9	12.0	2.5
5	4	0.75	-	5.0	4.9	1.9	6.0	-
6	2	0.75	-	-	-	-	2.0	-

- **Zone 3 : Ancillary accommodation**

This forms a grouping of circulation areas, bathrooms and utility room in which occupancy can be expected, on the whole, to be under one hours duration. There are therefore no heating gains from occupants, lighting or equipment. Heat gains from the hot water use in bathrooms are extremely difficult to estimate and some of this output is included in the figures for the airing cupboard [Bedrooms]. Heat gains from washing and drying clothes have been incorporated in the internal gains for Living Rooms. It has also been assumed that extract fans or ventilation ducts will be used in bathrooms and utility rooms in line with the revised Part F Ventilation regulations [Building Regulations (4)1995], thus reducing latent gains. There is a constant infiltration rate for the 24 hour period, set to take account of opening windows and doors, extract fans and ducts.
To avoid excessive data input which could lead to errors only one set of internal conditions has been compiled for Zone 3, as shown below:

Internal Conditions Datasheet Code:bsa/1 zone: 3
Location: ancillary areas/ week days and weekends / GMT and BST

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	18	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.00	8.00	size	
2	16.00	22.00	size	

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	24	1.0	-	-	-	-	-	-

Note: The “Time plant on” entry reflects the one hour period needed to bring the temperature up to the set point.

The sources for the internal gains data; hot water gains, infiltration, heating schedules and set points are included in Appendix D.

- **Zone 4 : Bedrooms**

In addition to occupancy gains, lighting gains, infiltration and heating for the bedrooms this zone also includes the heat output from the airing cupboard. This cupboard contains the hot water storage tank and is often located adjacent to at least two bedrooms. The heat output from the water tank and pipes is easier to include in the controlled total area of the bedrooms rather than the varying and much smaller, total area of the ancillary accommodation.
The internal conditions datasheets for the Bedrooms are shown on the following pages.

Note: The "Time plant on" entry reflects the one hour period needed to bring the temperature up to the set point.
The sources for the internal gains data; occupancy data, infiltration, heating schedules and set points are included in Appendix D.

- **Zone 5 : House roofspace**

This volume has a 24 hour infiltration rate of 1.5 ac/h, but no plant or incidental gains.

Internal Conditions Datasheet Code: bsb/1 Zone 4
Location:Bedrooms / weekday / GMT

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	18	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.00	9.00	size	
2	16.00	23.00	size	

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	7	0.75	-	-	7.7	4.1	6.0	-
2	12	0.75	-	-	-	-	6.0	-
3	4	0.75	-	5.0	3.8	2.0	6.0	-
4	1	0.75	-	-	7.7	4.1	6.0	-

Variation for BST Code: bsb/3

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	5.00	8.00	size	
2	15.00	22.00	size	

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	6	0.75	-	-	7.7	4.1	4.5	-
2	12	0.75	-	-	-	-	4.5	-
3	4	0.75	-	2.5	3.8	2.0	4.5	-
4	2	0.75	-	-	7.7	4.1	4.5	-

Internal Conditions Datasheet Code: bsb/2 Zone 4
Location: bedrooms / weekend / GMT

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	18	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.0	23.0	size	

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	7	0.75	-	-	7.7	4.1	6.0	-
2	12	0.75	-	2.5	2.45	1.0	6.0	-
3	4	0.75	-	5.0	3.8	2.0	6.0	-
4	1	0.75	-	-	7.7	4.1	6.0	-

Variation for BST Code: bsb/4

Temp. upper limit°C	Temp lower limit °C	Prop'nal control °C	On-off control °C	Hum'ty upper limit %	Hum'ty lower limit %	Plant max outside °C	Plant off outside °C
50	18	-	-	100	0	-	-

Operating period	Time plant on	Time plant off	Heating kW	Cooling kW
1	6.0	23.0	size	

Occupation		Infilt'n	Vent'n	Heat gains Watts/m^2				
period	hours	ac/h	ac/h	Lighting	Occupancy		Equipment	
					sensible	latent	sensible	latent
1	6	0.75	-	-	7.7	4.1	4.5	-
2	12	0.75	-	-	-	-	4.5	-
3	4	0.75	-	2.5	3.8	2.0	4.5	-
4	2	0.75	-	-	7.7	4.1	4.5	-

Checking the internal conditions and incidental gains

In order to check the acccuracy of the internal conditions data reference was made to the Technical Note: Standard Dwellings for Modelling [Allen and Pinney, 1991].
This gives two occupancy profiles for incidental gains for a 3-bedroomed house. Heavy occupancy represents a couple with two young children less than five years old, with the wife not working. The light occupancy represents a working couple with two school age children.

Table 2.07 **Incidental gains predicted for heavy and light occupancy together with those for the 90m^2 house model.**

	Predicted Heavy Profile kWh/day	Predicted Light Profile kWh/day	**90 m^2 model with 4 occupants** kWh/day
Occupancy	5.46	4.02	5.54
Lights	2.50	2.17	1.96
Equipment	10.93	8.48	10.5
Total	18.89	15.0	18.00

2.08 Building Constructions

The Tas Thermal Analysis system requires that building constructions, made up of the appropriate materials, be entered for all the different building elements, such as walls, roofs and floors, designated in the 3d - model.

Building materials
A data-base of coded building materials is supplied for this purpose but other materials can also be entered and coded, if required for a particular project.
The following physical properties are stored for each opaque material; thermal conductivity, density, specific heat capacity, vapour diffusion factor, emissivity for the surface at terrestrial temperatures, and solar absorptance.
For transparent materials the properties stored are; solar and light transmittance, solar and light, external and internal reflectances, external and internal emissivity, thermal conductivity and vapour diffusion factor.

Building constructions data sheets
A building constructions datasheet is compiled for each building element and consists of a list of the coded building materials occurring in the element, working from the internal face to the external face. The thickness of each material is also entered and from this and the corresponding physical properties of the component materials the program calculates the external and internal solar absorptance, external and internal emissivity, thermal conductance and time constant for an opaque construction.
For a transparent construction, the properties calculated are solar transmittance, external and internal solar absorptance, light transmittance, external and internal emissivity and conductance.
The U-value can also be calculated for any construction, though being a steady state figure this is not used by the dynamic simulation program.

The choice of building materials and constructions for the models
In order that this study should be relevant to building practice in the volume house building market, constructions entered for the building elements followed typical housebuilding practice and the external elements had U-values complying with the requirements of the Elemental Method of the 1995 edition of Part L of the Building Regulations - Conservation of Fuel and Power. [Building Regulations (6)]. Although these regulations did not come into force until July 1995, they were available from August 1994 and a draft document had been in circulation prior to this.
Datasheets of the building constructions used for this study are included in Appendix E.
Brief descriptions are included overleaf, followed by the reasoning behind the choice of materials.
The U values shown were calculated by the A -Tas program using CIBSE parameters for opaque constructions and data from Pilkingtons, the glass manufacturers, for glazing.

The Construction Materials for the Glazed Space

Glazing materials for the external walls and roof

During the thermal simulations three options were tested for the glazing materials for the roof and walls of the glazed space;

1. **Single glazed walls and double glazed roof**
2. **Double glazed walls and roof**
3. **Low emissivity [low E] glazed walls and roof**

The range of glazing for the glazed space was compiled from the types of glazing offered by conservatory manufacturers.
Single glazing is the cheapest and also the lightest option for roofs, leading also to savings in the size and strength of the framing members. However, problems do occur with condensation on the inner face of single glazed roofs due to radiation to the cold night sky. This can be overcome by combining single glazed walls with the increased insulation of a double glazed roof.
A lighter alternative to double glazing is the use of twin or triple layer polycarbonate sheeting, also offered by conservatory manufacturers. A major disadvantage of the use of polycarbonate sheeting is the expansion and contraction caused by changing exposure to solar heat gain, and the cracking noise which this creates. Rain also creates a heavy drumming noise.
Simulations carried out for the MSc thesis [Swann,1991 p85-86] showed that this type of sheeting performed in a similar way to double glazing both in terms of insulation value and its effect on air temperatures in the glazed space.
To avoid over complication of the variables for testing, the first glazing option was designated as single glazed walls and a double glazed roof.
Double glazing for both walls and roof was chosen as the second option as this combination has often been put forward in conservatory manufacturers literature as being a worthwhile measure.
Recently, as noted in Chapter 1.04, the manufacturers have been responding to criticism of low temperatures in their conservatories by recommending the use of low emissivity, ie. low E, glazing for walls and roofs. This type of glazing involves the incorporation of a layer of low emissivity material on the cavity face of the inner pane of double glazing, which reduces heat loss from the internal space. The third option for glazing has therefore been designated as double glazing with a low emissivity coating.

The specifications for the glazing types and the U values, calculated by the Tas program from data supplied by Pilkingtons the glass manufacturers, were as follows;

- Single glazing : 6mm glass, U value=5.37 W/m^2C
- Double glazing : 4mm glass /12mm cavity /4mm glass, U value=2.80 W/m^2C
- Low Emissivity glazing : 4mm low E coated glass /12mm cavity /4mm glass, U value=1.78 W/m^2C

The insulating blind to the glazing

Insulating blinds were added to the glazing for a second series of simulations in order to assess their possible effectiveness in reducing the heating loads for the glazed spaces.

The material for the insulating blind was based on a flexible insulant, [tradename, Alreflex 2L2] in the form of a 6mm thick polyethylene bubble sheet [containing air] laminated on both sides with aluminium foil. This material is not marketed as a conservatory blind material, it would be bulky when rolled or folded but it would be easier to handle than solid sheets of insulation. A datasheet for the material was compiled, and the code for this information added to copies of the construction datasheets for the glazing options for the glazed spaces, in the form of an internal blind.

For the double glazing the addition of the insulating blind reduces the U value from 2.8 W/m^2K to I.51 W/m^2K
For the low E glazing the addition of the insulating blind reduces the U value from 1.78 W/m^2K to 1.16 W/m^2K

Internal or external shading blinds to the glazing

Shading blinds, internal or external, were added to the double glazing for a series of simulations in order to assess their effectiveness in reducing the occurrence of high temperatures in the glazed spaces

The glazed space floor construction and finish

- carpet / screed / concrete slab / hardcore / clay soil,
  U value=0.29 W/m^2C [including 2.0 metres of soil]

Floors of conservatories are generally constructed as a hardcore base covered by a concrete slab which will have been powerfloated or screeded to provide a smooth finish suitable for a tiling, sheeting or carpeting.
A floor slab with a finish of stone or concrete paving slabs or quarry tiles will absorb incident solar radiation and take in heat from the air if the air is at a higher temperature than the slab. The stored heat will then be transferred back to the air as the room temperature falls. In this way the thermal mass of the solid walls and floor slab can theoretically reduce the large temperature swings experienced in conservatories. A carpet finish isolates the thermal storage properties of the concrete floor slab from the internal environment and so reduces its ability to reduce temperature swings. Furnishings will also shield the slab from incident radiation. However the survey of conservatory owners [Moon,1991] found that carpeting or rugs were used as the floor finish by 60% of respondents. A thin carpet layer was therefore used as the finish for the floor of the glazed space in all the initial simulations.

A further study was later undertaken to assess the effect on resultant temperatures of the thermal storage properties of a similar floor construction finished with a layer of clay tiles.

- clay tiles / screed / concrete slab / hardcore / clay soil
  U value=0.3 W/m^{2}C [including 2.0 metres of soil]

The dividing wall between the glazed space and the house

The dividing wall was designated as an external wall with the construction as for the house external wall noted above. In the case of a single storey, add-on type of conservatory it is unlikely that the wall construction would be changed to a cheaper type such as a single layer of blockwork since the weatherproofing provided by the external brick leaf would need to be maintained at the junctions with the glazing, particularly the horizontal roof junction. Maintenance of the insulating value of the wall, a maximum U value of 0.6 W/m^{2}K, in compliance with the Building Regulations would also be necessary. [Building Regulations(6)]

It can be argued that in the case of a recessed glazed space with three dividing walls between the house and the glazed space, the dividing walls would be constructed of solid, thermally insulating blockwork. However it was decided that the dividing wall construction would remain as an external wall, in order to maintain the same thermal storage properties of the dividing walls throughout the comparative simulations.

Openings in the dividing wall

For the single storey glazed space a double glazed patio door, 1.5 m. wide was inserted in the dividing wall.

For the two storey glazed space, a double glazed patio door, 1.5 m. wide was inserted in the dividing wall on the ground floor and a double glazed window, inserted on the first floor, between the glazed space and the bedroom zone.

In the houses without a glazed space these then became external windows and doors.

Building Constructions for the House

Datasheets of the building constructions used for this study are included in Appendix E.
Brief descriptions only are included below.
The U values shown were calculated by the A -Tas program using CIBSE parameters for opaque constructions and data from Pilkingtons, the glass manufacturers, for glazing.

House external walls:
- flat white paint / lightweight plaster / concrete blockwork / glass fibre insulation / cavity / facing brickwork
  U value=0.43W/m^2C [Regulations maximum U value=0.45 W/m^2C]

House roof with insulation at first floor ceiling level
- flat white paint / plasterboard / glasswool insulation
  U value=0.245 W/m^2C [Regulations maximum U value=0.2 or 0.25 W/m^2C]
  + roofspace / sarking felt / clay roof tiles

House roof with insulation between sloping ceiling and roof tiles
- flat white paint / plasterboard / glasswool insulation / cavity / sarking felt / clay roof tiles
  U value=0.33 W/m^2C [Regulations maximum U value=0.35 W/m^2C]

House ground floor
- carpet / underlay / chipboard / polystyrene insulation / concrete slab / hardcore / clay soil
  U value=0.21 W/m^2C [including 2.0 metres of soil]
  [Regulations maximum U value=0.35 or 0.45W/m^2C]

House, ceiling to ground floor / floor to first floor
- flat white paint / plasterboard / cavity / chipboard / underlay / carpet

House internal walls
- flat white paint / lightweight plaster / lightweight concrete block / lightweight plaster / flat white paint

House window and door glazing
- 4mm glass / 12mm cavity / 4mm glass
  U value=2.80 W/m^2C [Regulations maximum U value - area dependent]

Typical window sizes were used and the total area of windows and doors kept within the maximum set out in the Building Regulations for double glazing. [Building Regulations(6)]

2.09 The Selection of Weatherfiles for the Thermal Simulations

The Tas system supplies weather-files for many areas of the world. The areas covered in England, Wales and Scotland are shown on the map in Appendix F. As this study is concerned with the private house building market, it was necessary to choose weatherfiles for the simulations, applicable to the regions of highest level of private housebuilding.

The weatherfiles chosen for the simulations were as follows;

South-east weatherfile

The National Home Building Council (NHBC) publish a quarterly review, 'Private House Building Statistics'. This lists the number of houses for which the building process began or was completed during the quarter, as notified to the NHBC by the house builders. [NHBC, 1991]

For the fourth quarter of 1991, the area of the England, Wales and Scotland which had the highest number of 'starts' was the south- east of England which, together with the Greater London Area, totaled 34,360 or 27% of the total figure for the three countries.

The Tas south-east weatherfile area shown on the map in Appendix F, corresponds with the NHBC south -east area which encompasses Bedfordshire, Berkshire, Buckinghamshire, East Sussex, Essex, Hampshire and the Isle of Wight, Hertfordshire, Kent, Oxfordshire, Surrey and West Sussex with the addition of the Greater London Area. The Tas south-east weatherfile was therefore chosen for the first set of simulations.

North-west weatherfile

The area with the next highest number of starts listed in the NHBC review, is the north-west of England with a total of 14,270, and which includes Greater Manchester, Merseyside, Cheshire and Lancashire. The highest number of starts in Scotland occurred in the Strathclyde region in western Scotland and totaled 5,620. Together the north-west of England and the Strathclyde region represented 16% of the total number of starts for England, Wales and Scotland. The Tas north-west weatherfile was therefore chosen for the second set of simulations, for the first thermal model. As can be seen from the map in Appendix F, this covers the north-west area of England and also south-western Scotland, and provides a contrast in weather patterns and temperatures to that provided by the south-east weatherfile.

Information regarding the weatherfiles is included in Appendix F

2.10 The Strategy for Simulation of Buoyancy Driven Ventilation

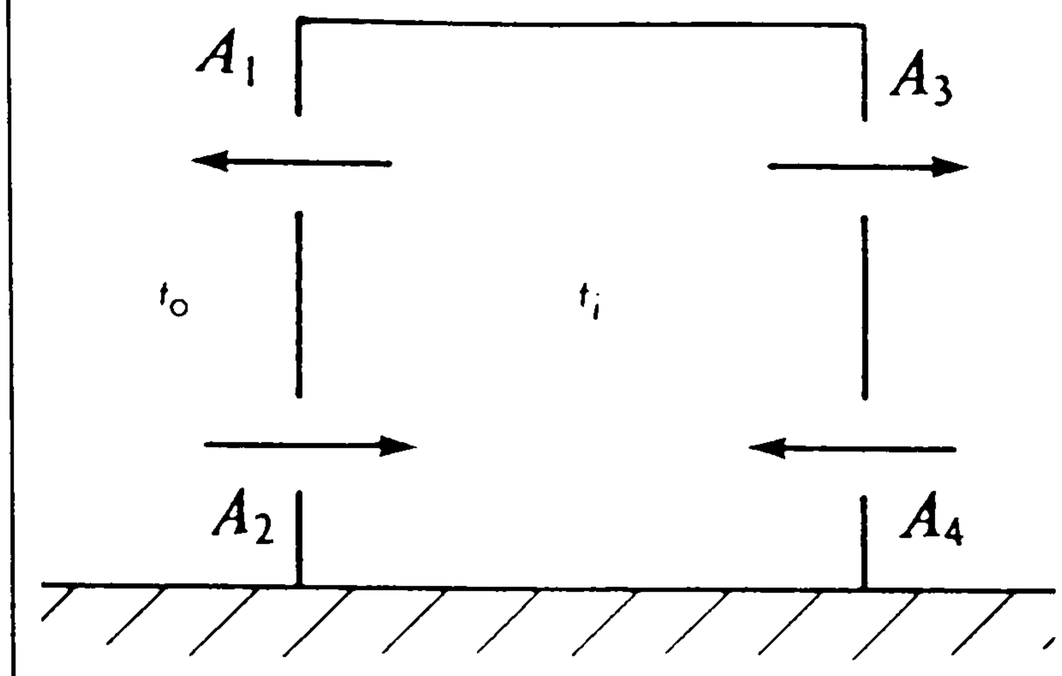
As discussed in the introductory chapters several sources advocate the use of ventilation through high and low level openings as a means of reducing uncomfortably high temperatures in glazed spaces, though no specific recommendations on areas and positioning of the openings have been found. The high level openings provide a route for rising, warmed and therefore less dense, air to escape from the space, drawing in external cooler air, through the low level openings as it does so. The simulation of this cooling effect produced by the incorporation of high and low level ventilators in the design of the glazed spaces was therefore investigated as an additional study.

Development of the strategy

The A -Tas program deals with the introduction of external air into a zone by the designation of air change rates for infiltration and mechanical ventilation, for up to eight periods of the day as shown in the Internal Conditions datasheets.
The problem for this study was how to ascertain the air change rates which could be achieved, by the buoyancy effect, in the glazed space under test, and to model the interaction between air change rate and internal and external air temperatures.
Buoyancy driven ventilation is promoted by the difference in temperature between internal and external air. As the incoming, cooler external air replaces the warmed air, the internal air temperature is reduced, leading to a drop in the air change rate and a consequent reduction in the amount of cooler air introduced. Therefore applying a fixed air change rate to a simulation model will not provide a very accurate estimation of the interrelated effect of temperature and ventilation. A more adaptive method is required, particularly for a glazed space, in which the internal temperature reacts rapidly to the effect of incident solar radiation.
The CIBSE Guide, Section A4 [CIBSE,1986] gives a correlation, shown overleaf, Figure 2.08, for the estimation of an air change rate, achievable by stack [or buoyancy driven] ventilation through high and low level openings. This correlation was used as the basis for an iterative process, developed by Dr W Batty of Cranfield University, which enabled average, achievable air change rates to be calculated for different periods of the day. These rates were then used in the simulations to obtain an estimate of the effect of buoyancy driven ventilation on overheating in the glazed spaces, as described below.

The ventilation simulation strategy

The models for the glazed spaces were studied and reasonable areas for high and low level openings and a maximum height from centre to centre were calculated. A range of typical internal and external temperatures were chosen and substituted, in turn, into the above correlation together with the dimensions for area and height difference. Thus a range of air change rates was achieved and a graph drawn up plotting air change rates against temperature difference [between internal and external air temperature], Figure 2.09.



$$Q_B = C_d A_B \left(\frac{2 \Delta t \, h_a \, g}{(\bar{t} + 273)} \right)^{0.5}$$

$$\frac{1}{A_B^2} = \frac{1}{(A_1 + A_3)^2} + \frac{1}{(A_2 + A_4)^2}$$

A_B = equivalent area for ventilation by stack only
Cd = discharge coefficient
Q_B = volume flow rate due to stack effect only
g = gravitational constant
h_a = height of air column
t_i = mean inside air temperature
t_o = outside ambient temperature
Δt = difference between t_i and t_o
$\bar{t}$ = mean of temperature t_i and t_o

Figure 2.08 **The CIBSE correlation for stack effect ventilation**

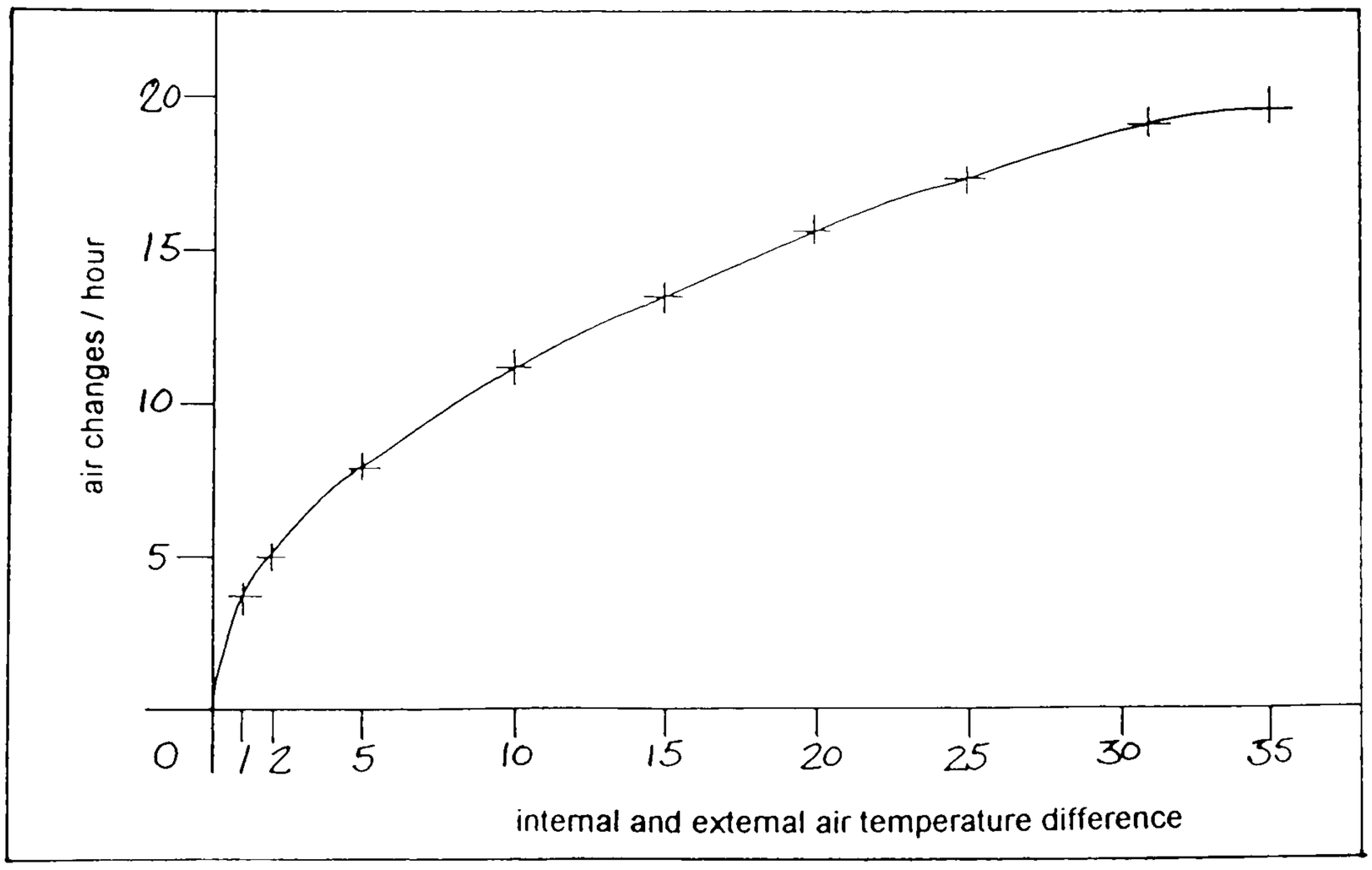


Figure 2.09 **Graph of air change rates against temperature difference for the 0.15m^2 area ventilation openings**

A suitable day was chosen, from the weatherfile and a one day thermal simulation performed for the basic model with no ventilation in the glazed space, purely infiltration through the fabric.

The day was divided into periods during which the external air temperature remained reasonably constant. Average values for the external air temperature within each period were calculated. Average values for the internal air temperature in the glazed space, as predicted by the simulation results, were also calculated for each of the periods. The average external air temperatures were then deducted from the average internal air temperatures to give a temperature difference for each period of the day. The corresponding air change rates were then ascertained from the previously prepared graph of air change rates plotted against temperature difference.

These air change rates were then inserted into the internal conditions for the glazed space and the one day thermal simulation repeated. Predicted internal air temperatures were again averaged out during the set periods and the differences between internal and external air temperatures calculated. A revised set of air change rates corresponding to the temperature differences were then ascertained from the graph and these values again inserted into the internal conditions and the day simulation repeated.

It was noted that with successive simulations the values for temperature difference and air change rate, for each period, oscillated in a diminishing fashion. This iterative process was repeated several times until the internal temperatures were predicted to within 0.1^{o} C for successive simulations. This process then gave an estimate of the air change rates, which could be achieved on specific days, using ventilation openings of the dimensions inserted in the correlation. The detailed application of this method to this study of glazed spaces is described in Chapters 3.04 and 4.04.

CHAPTER 3

The First Set of Thermal Models, Based on a Single Storey Glazed Space

3.01 Description of the Model

The first thermal model consisted of a single storey glazed space, constructed against one face of a medium sized detached house. The model was intentionally simple in order that it could be used to test the thermal simulation strategy, described in Chapter 2.04, at each stage, in addition to providing the simulation results for the single storey glazed space.

A house of 90m^2 total internal floor area, typical of a three bedroomed, detached house was set up with the addition of a single storey glazed space, of 9 m^2 floor area. The design of the house and glazed space is shown in Figure 3.01, overleaf.

Zones were designated as shown in Table 3.01 below and discussed in Chapter 2.07, on Zoning and Internal Conditions.

Table 3.01 **Zones in the 90m^2 model**

Zone 1 :Glazed space	9m^2	20% of ground floor area
Zone 2 :Living areas	38m^2	includes living room, dining room, kitchen
Zone 3: Ancillary areas	7m^2 ground floor 10m^2 first floor	areas of fleeting occupancy, includes circulation, bathroom
Zone 4 :Bedroom areas	35m^2	includes bedrooms and airing cupboard
Zone 5 :House roofspace		

Design of the glazed space

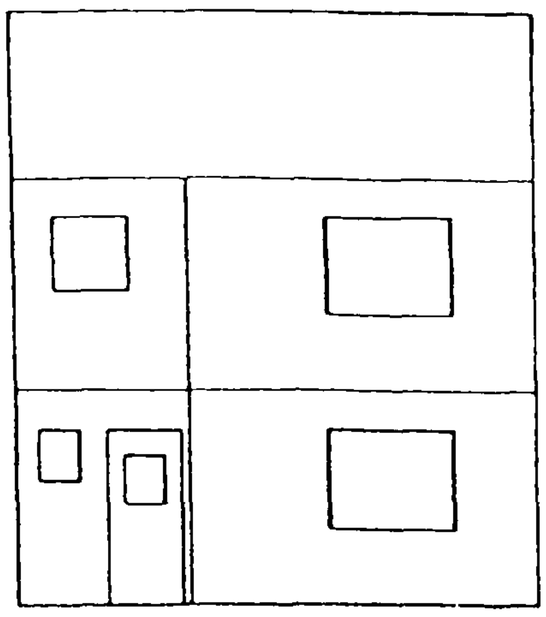
The glazed space was positioned symmetrically on the house facade and had a glazed roof, fully glazed walls and internal dimensions of 3.3m x 2.7m. The pitch of the roof, 19°, was chosen so that the apex of the roof would fit below the level of first floor window cills.

Positioning of the house windows

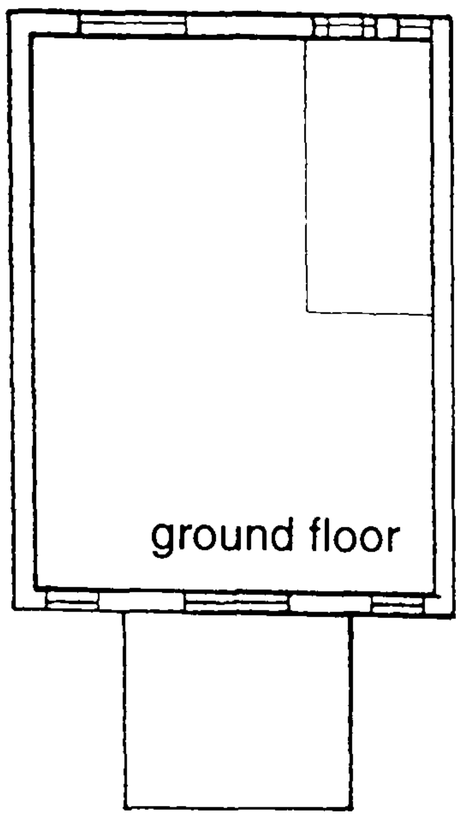
Care was taken to arrange the house windows symmetrically on each facade, with a close match in area on the front and back of the house in order to keep exposure to solar radiation consistent for different orientations. Positioning windows on the sides of the house was avoided as they limit the positioning of houses on a site layout. A glazed, patio type door was positioned in the centre of the dividing wall linking the house and the glazed space. With the glazed space removed in the basic house model, the door became an external door.

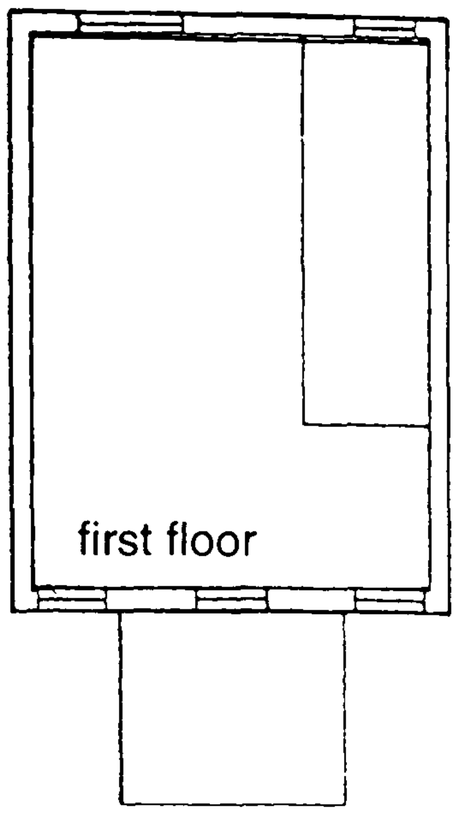
Completion of the models

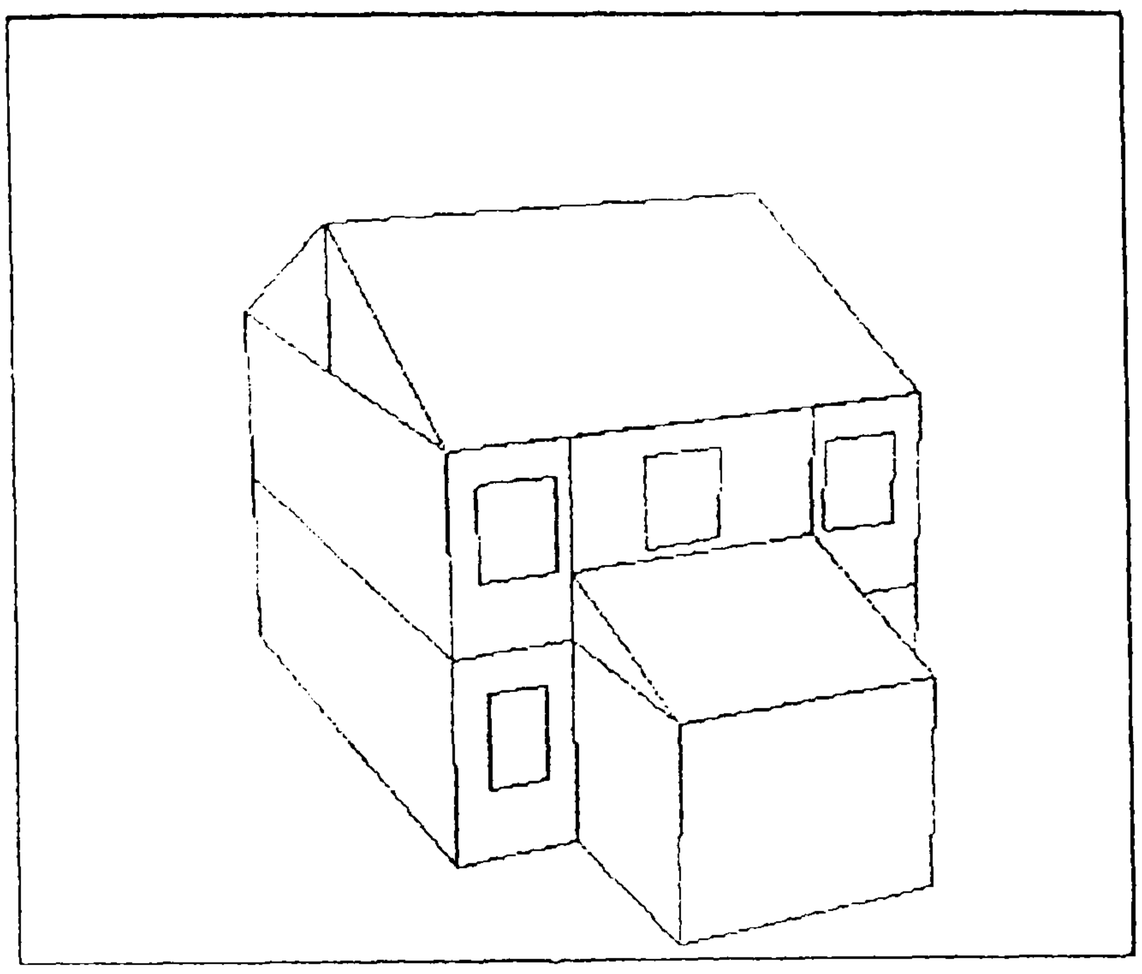
The thermal simulation strategy was then worked through and amended as necessary until the multiple building models were complete geometrically and with building constructions and internal conditions added, as described previously.



entrance elevation







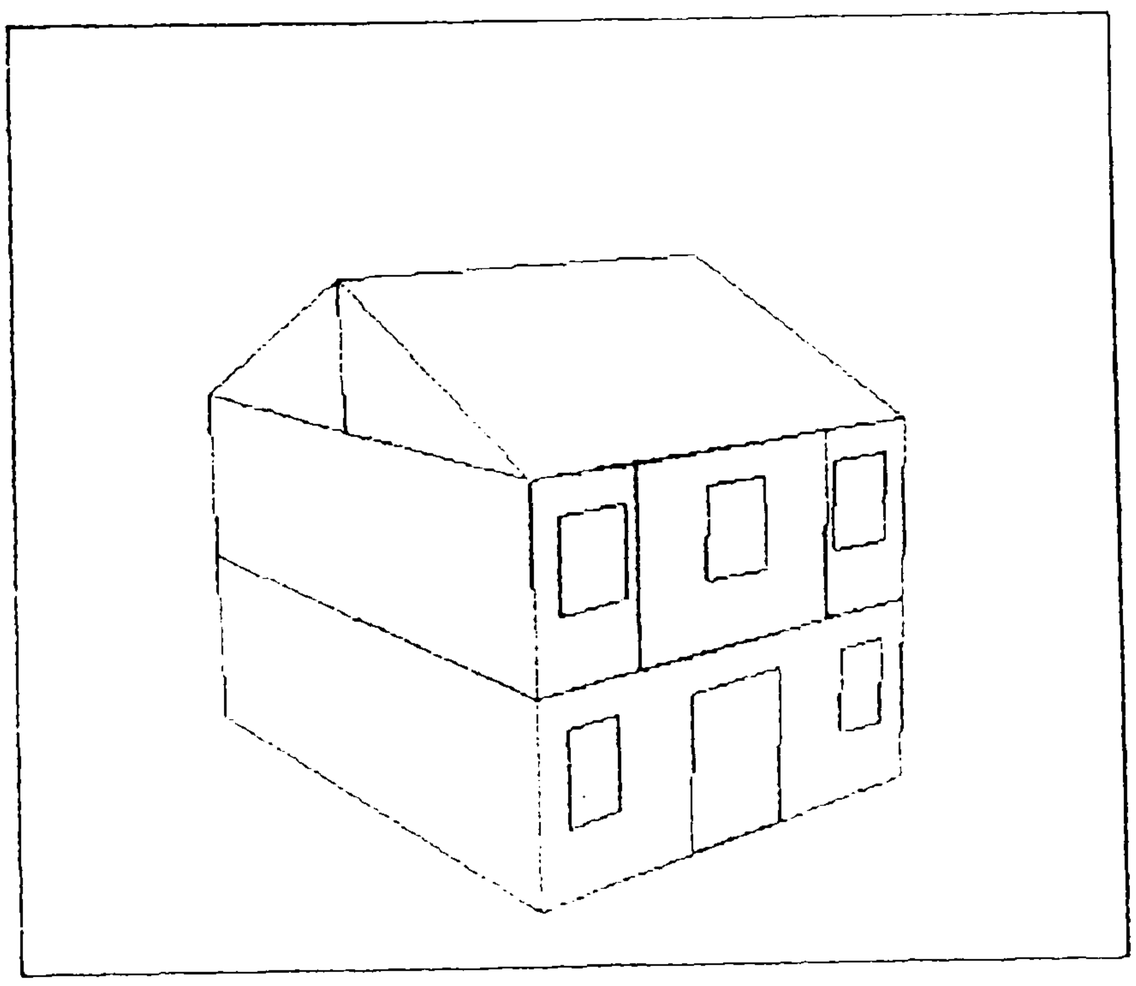


Figure 3.01 **90m^2 model with and without a glazed space**

3.02 Initial Simulations

Initial thermal simulations were then undertaken for the full matrix of models, using the weatherfile for the south-east of Britain. The approach to air infiltration and air movement in these initial simulations is outlined below.

Air infiltration and air movement

For the initial simulations, outside air entered the interior spaces only by infiltration through the building fabric, at rates set out in the internal conditions data -sheets, Chapter 2.07. No attempt was made at this stage to simulate ventilation by opening windows and doors. The results of these simulations provided a standard for comparison with the results of further studies, described later, in which strategies to enhance the performance of the glazed space in terms of a comfortable low energy environment were incorporated.
Air movement between the zones was not included in the simulations.

Simulation results

Simulation results were obtained for **the house with an unheated glazed space**, for four orientations and three glazing types for;

- the number of hours of comfortable temperatures in the glazed space, on a yearly basis and on a monthly basis
- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in the living rooms

Simulation results were obtained for **the house with a heated glazed space,** for four orientations and three glazing types for;

- the monthly space heating load for the house
- the monthly space heating load for the glazed space

Simulation results were obtained for **the house without a glazed space** for;

- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in living rooms

3.03 Presentation of the Results of the Initial Simulations

The results of the initial simulations and discussion of the implications are presented as follows;

- Comparison of the number of comfortable hours in the unheated glazed spaces on a **yearly** basis, Figure 3.02 and on a **monthly** basis, organised by orientation, Figures 3.03 - 3.06.

- Comparison of the annual space heating loads of the basic house and the house with a heated or unheated glazed space, Figure 3.07

- The effect of the presence of the glazed space on overheating in the adjoining living rooms, Figure 3.08.

Identification of the models
In the presentation of the results the models are identified by the orientation and glazing materials of the glazed space, for example;

north single, east double, west low E

where the glazing materials are as follows;

single : single glazed walls and double glazed roof

double : double glazed walls and roof

low E : double glazed, low emissivity, walls and roof

Results of the initial simulations

Comparison of the number of comfortable hours in the unheated glazed spaces on a yearly basis, using the south-east weatherfile

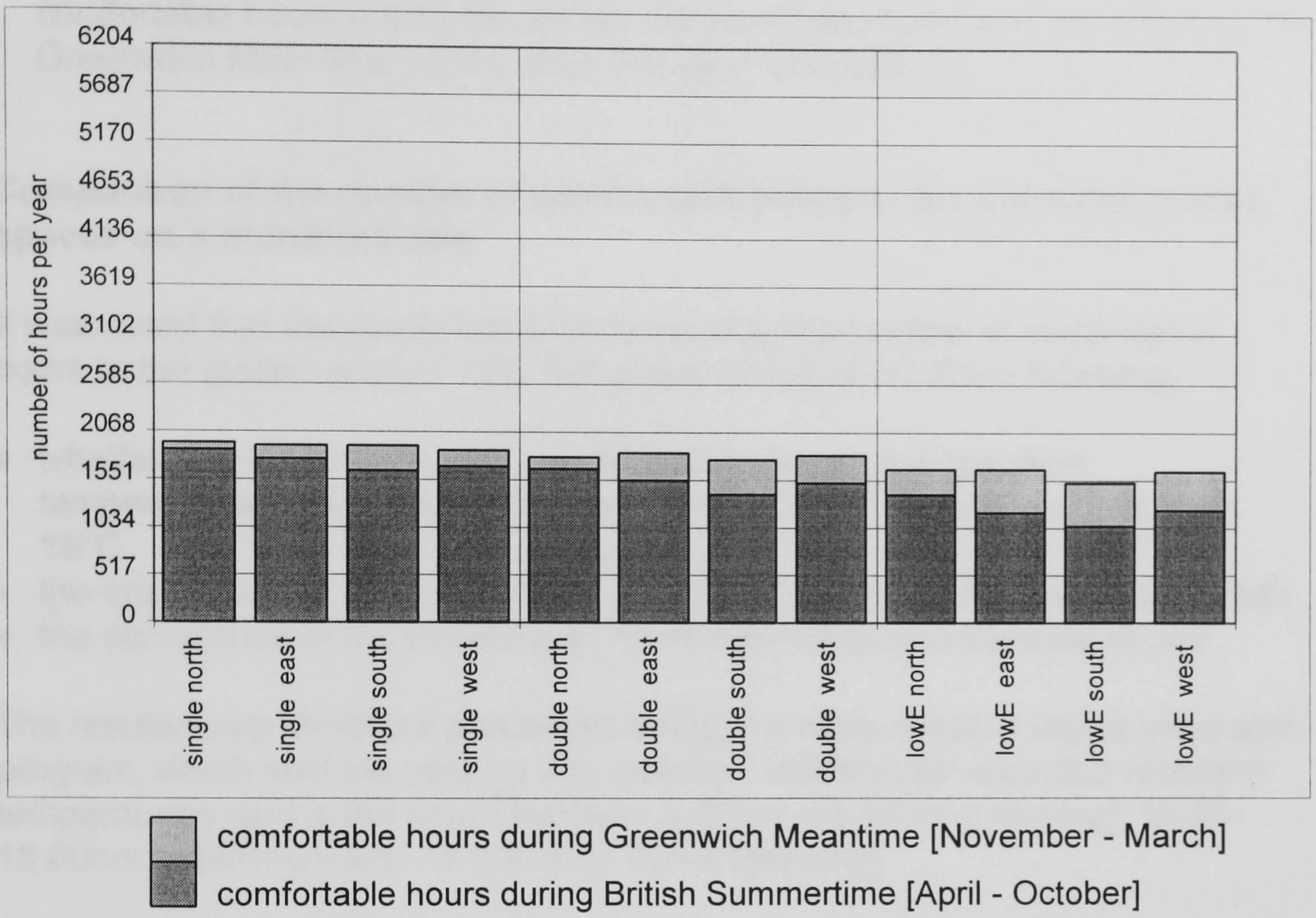


Figure 3.02 **The number of comfortable hours per year in the unheated glazed spaces**

The above chart gives the results of the initial checks on resultant temperatures in the unheated, unventilated, glazed spaces. Comfortable hours are defined as having a resultant temperature greater than 16°C and less than 27°C.
The temperatures were checked hourly between 6.00 hours and 23.00 hours, [17 hours per day] for a year, divided into Greenwich Meantime and British Summertime periods. The vertical axis represents one whole year and is divided into 12 nominal months [517 hours per month] and so gives a broad picture of the usable proportion of the year for each glazed space, if all the usable hours were consolidated.

The chart indicates that, in an unheated, unventilated mode;

- the glazed spaces are only usable for 25% to 31% of the year or approximately 3 - 4 months.
- the north facing, single glazed space has the highest total number of comfortable hours and these are predominantly in the British Summertime period.

- the south facing low E glazed space has the least number of comfortable hours but does have the largest number of comfortable hours during the Greenwich Meantime period, when compared with all the other models.
- within each glazing type, the total number of comfortable hours are very similar for all orientations, with the south facing orientation having fewer comfortable hours during the British Summertime period and more during the Greenwich Meantime period, than the other orientations.

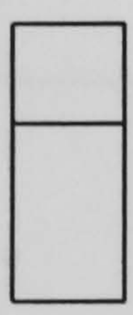
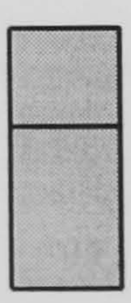
Comparison of the number of comfortable hours in the unheated glazed spaces on a monthly basis

It was noted that the yearly basis for assessing the number of comfortable hours in the glazed spaces does not give any indication of the following;

- whether the hours outside the comfortable range have resultant temperatures which are too hot, greater than 27°C, or too cold, less than 16°C.
- the occurrence of the comfortable hours with respect to the particular month
- the occurrence of the comfortable hours with respect to the time of day

The results were therefore processed through a more detailed report generator program, which split the year up into calendar months and recorded resultant temperatures during the hours between 8.00hrs -13.00hrs [morning], 13.00-18.00hrs [afternoon] and 18.00hrs-23.00hrs [evening].

The results are presented in Figures 3.03- 3.06 on the following pages.
The charts are organised by orientation and compare the effects of the choice of glazing on the number of hours of comfortable temperatures per month which can be achieved during the daytime, [morning and afternoon results added together] and evening periods.
The charts also indicates the hours which are too cold and those which are too hot, as shown in the key below;

too cold	comfortable	too hot
resultant temperature< 16°C	resultant temperature between 16°C and 27°C	resultant temperature> 27°C
 evening morning and afternoon	evening morning and afternoon	 evening morning and afternoon

The morning and afternoon results are combined as periods of use of a glazed space during the daytime are difficult to predict. Division of the daytime period would also lead to complications in reading the charts. A breakdown of the daytime period is included later, in Table 3.02.

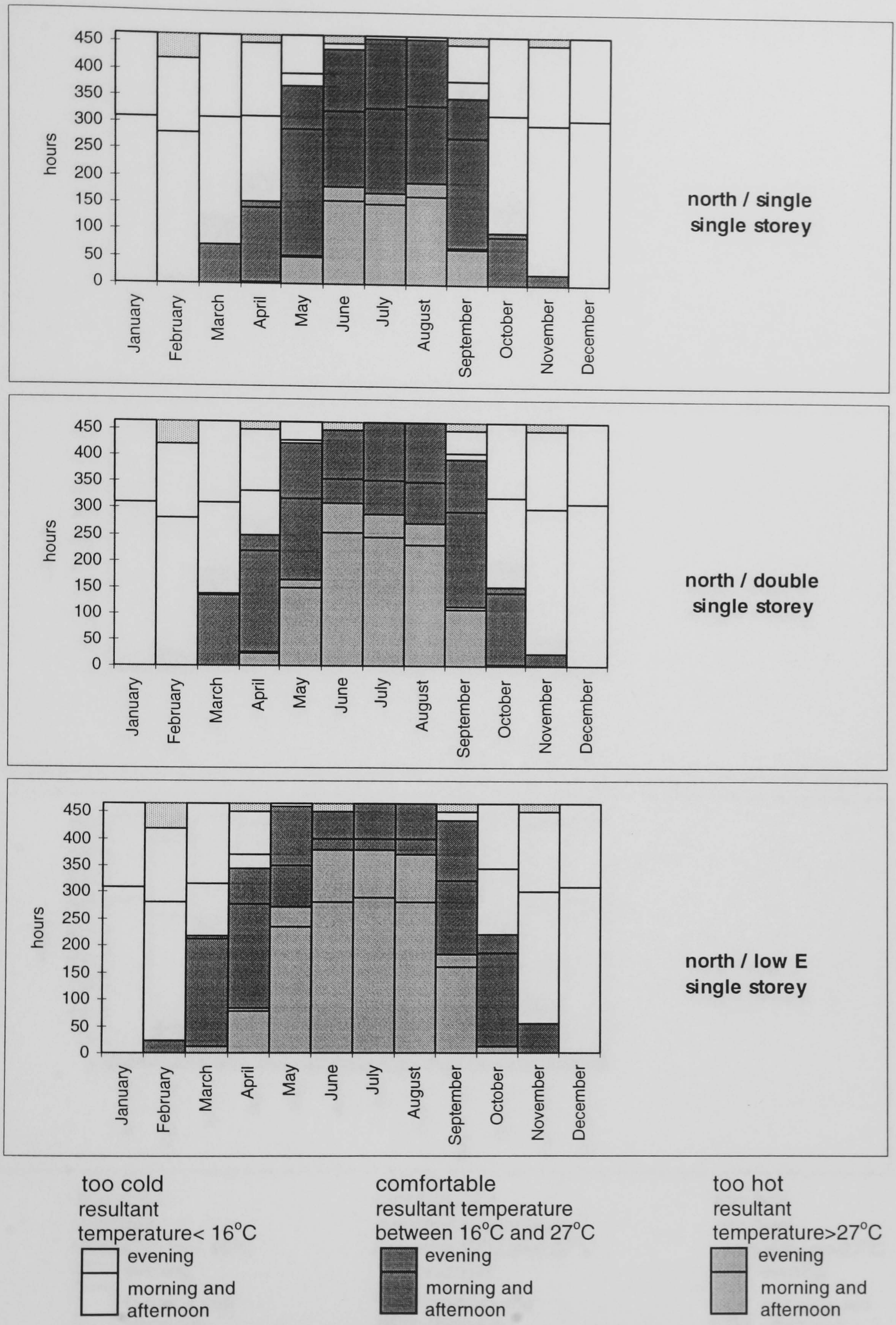


Figure 3.03 **Resultant temperatures in the north facing glazed spaces**

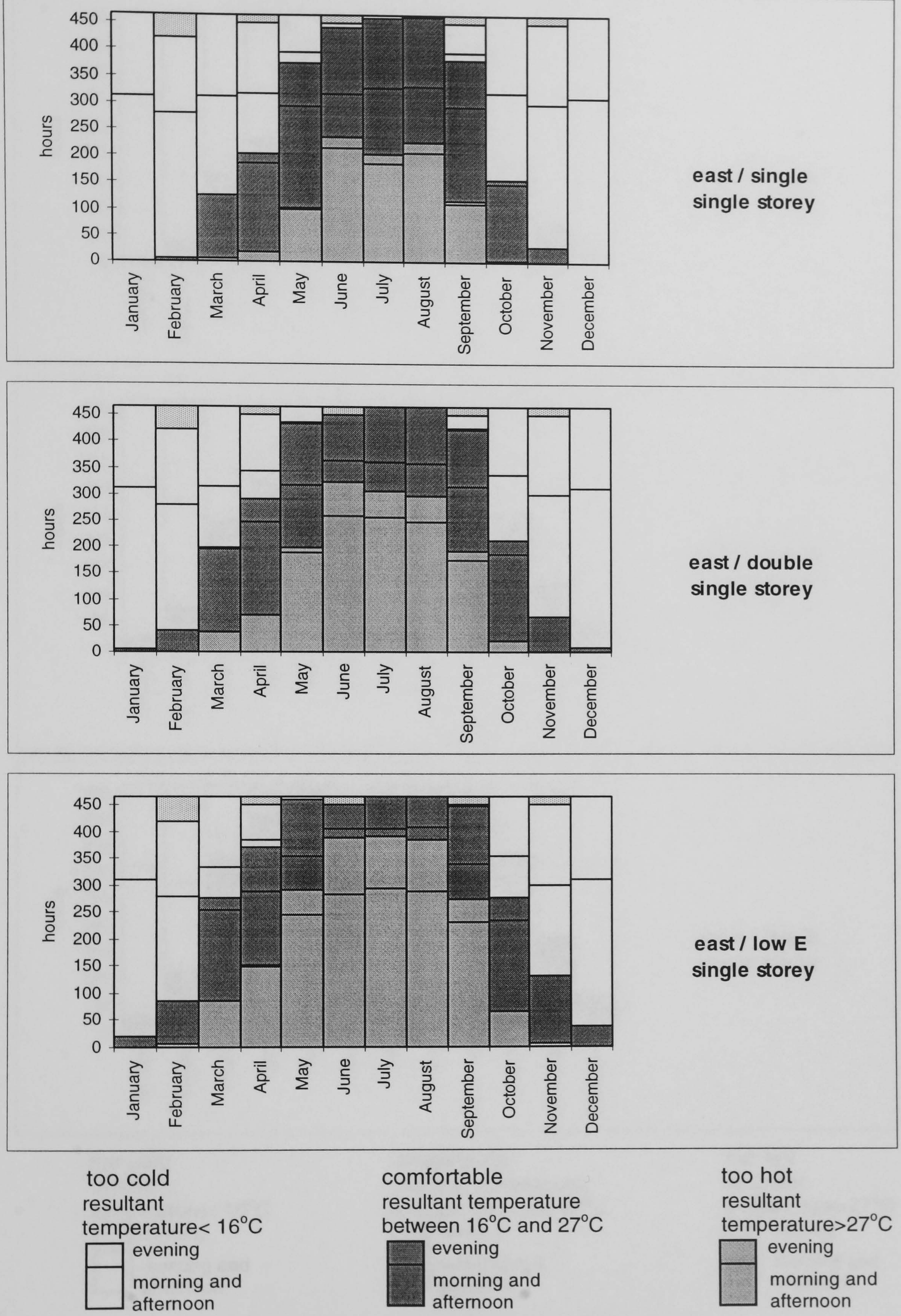


Figure 3.04 **Resultant temperatures in the east facing glazed spaces**

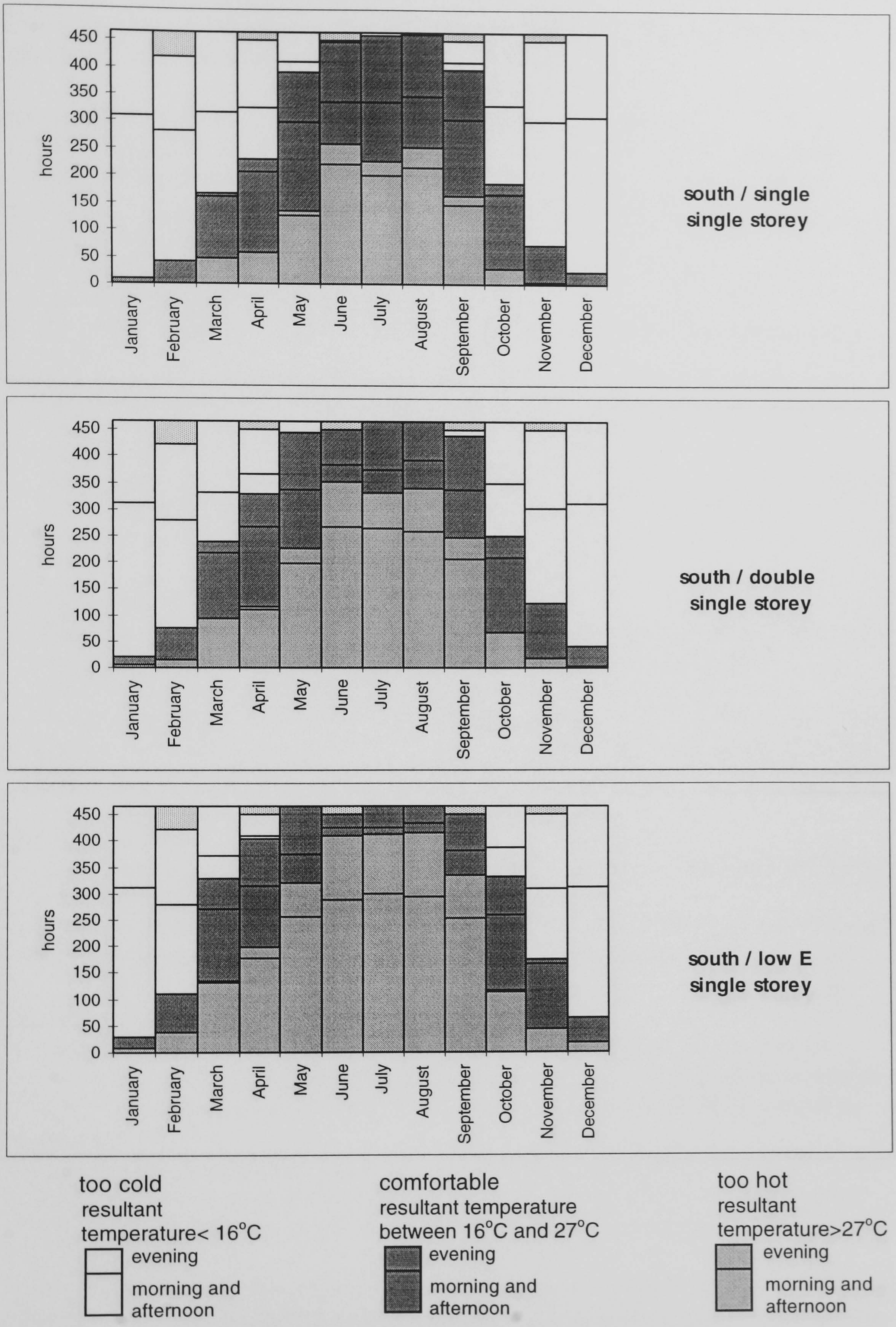


Figure 3.05 **Resultant temperatures in the south facing glazed spaces**

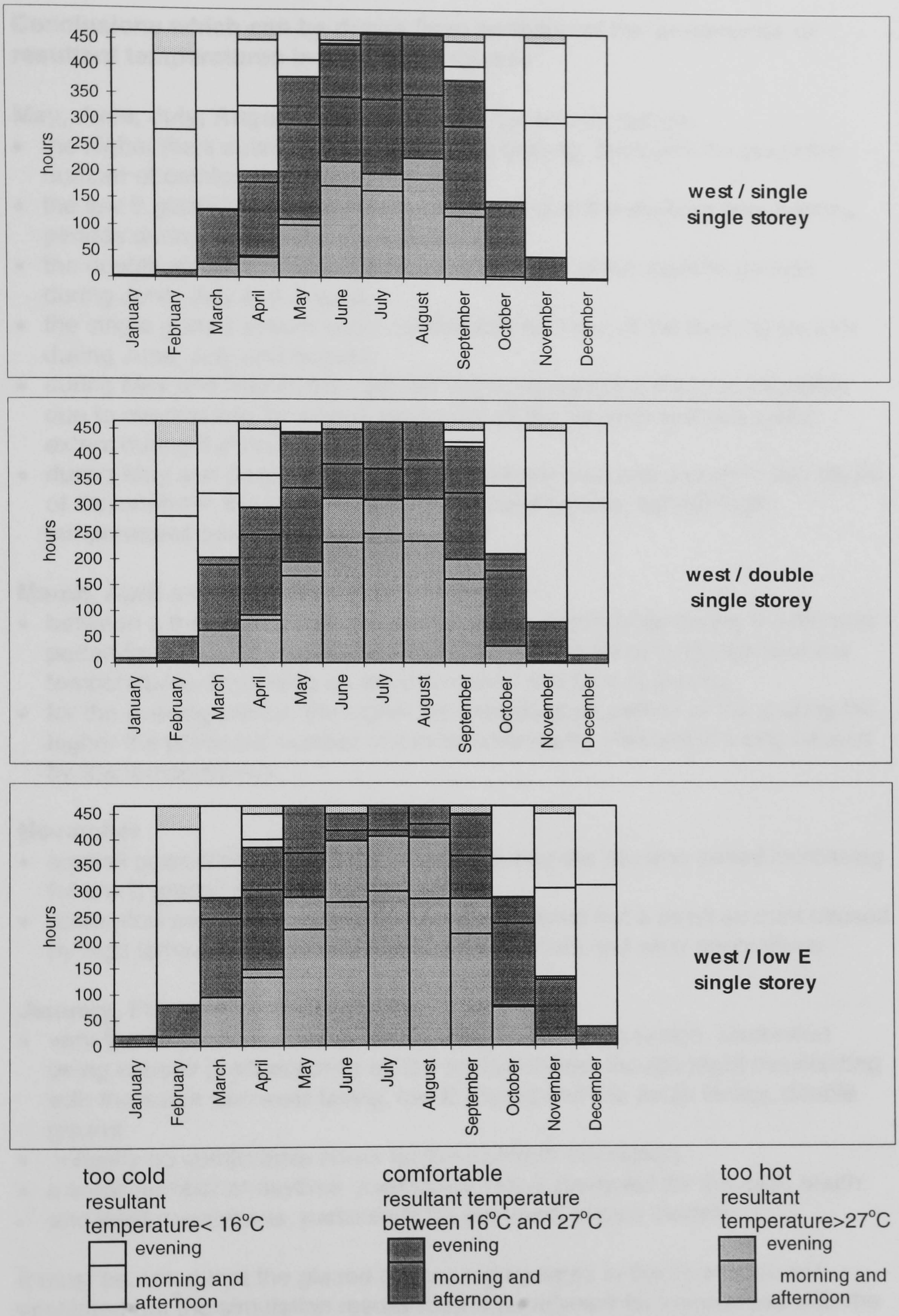


Figure 3.06 **Resultant temperatures in the west facing glazed spaces**

Conclusions which can be drawn from analysis of the predictions of resultant temperatures in the glazed spaces

May, June, July, August and September, for all orientations:

- the higher the insulating properties of the glazing, the lower the predicted number of comfortable hours.
- the low E glazed spaces were too hot for most of the daytime and evening periods during June, July and August.
- the double glazed spaces were too hot for most of the daytime periods during June, July and August.
- the single glazed spaces were comfortable for most of the evening periods during June, July and August.
- during May and September, the low E glazed spaces were uncomfortable due to overheating for a large proportion of the daytime and to a lesser extent during the evening period.
- during May and September, both high and low temperatures were the cause of discomfort in the single and double glazed spaces, though high temperatures predominated in the latter.

March, April and October, for all orientations:

- between a third and a half of the hours were comfortable during the daytime period for all glazing types, discomfort being caused by both high and low temperatures depending on the orientation and type of glazing.
- for the evening period, the higher the insulating properties of the glazing the higher the predicted number of comfortable hours, discomfort being caused by low temperatures.

November :

- a small proportion of comfortable hours,during the daytime period increasing for low E glazed spaces.
- discomfort generally caused by low temperatures but a small amount caused by high temperatures for the low E glazed, south and west orientations

January, February and December :

- very few comfortable hours, none during the evening period, discomfort being caused predominantly by low temperatures, though slight overheating with the south and west facing, low E glazed and the south facing, double glazed.
- virtually no comfortable hours for the northern orientation.
- a small number of daytime comfortable hours predicted for the east, south and west orientations, particularly for the low E glazed models.

It must be noted that the glazed spaces represented in the charts are not ventilated but the simulation results form a benchmark for comparison with the results of further studies which investigate the effect of ventilation on the number of comfortable hours predicted.

For clarity the charts on the previous pages show the number of comfortable hours in the morning and afternoon periods combined into one daytime figure. The shaded columns in Table 3.02 below, express the comfortable hours for each period of the day as a percentage of the total number of hours for that period over the course of a year. They show that within the daytime figure, the morning period always has a higher percentage of comfortable hours than the afternoon period. This information is useful to a certain extent but pinpointing the utility of a glazed space so specifically would, in practice, only be relevant to a small proportion of users.

Table 3.02 **The annual percentage comfortable hours for specific periods of the day**

	Percentage of morning hours which are comfortable	Percentage of afternoon hours which are comfortable	Percentage of evening hours which are comfortable	Percentage of morning+ afternoon hours which are comfortable [daytime]	Percentage of morning + afternoon + evening hours hours which are comfortable
north single	36	30	30	33	32
east single	32	31	32	31	32
south single	35	27	32	31	31
west single	36	27	30	32	31
north double	30	25	31	28	29
east double	30	26	33	28	29
south double	30	23	31	27	28
west double	35	23	29	29	29
north low E	28	23	28	26	26
east low E	27	23	29	25	26
south low E	24	20	27	22	24
west low E	30	20	26	25	25

The above table shows that whatever period or combination of periods of the day are studied, for an unventilated glazed space, the single glazed [double glazed roof] option provides the highest percentage of comfortable hours over the year and the low E glazed option the least.
Looking at the periods separately shows the effect of orientation.The lowest proportion of usable hours occur when solar radiation is incident on the major facade and the roof of the glazed space, showing that the glazed spaces respond rapidly to solar gain and become uncomfortable. For instance the table indicates that, an unventilated single glazed space is least comfortable during the morning if facing east and that north and east facing glazed spaces are more comfortable during the afternoon than those facing south and west.
The figures for the morning + afternoon + evening periods, taken as one, even out the differences between the orientations but still show the effect of the insulating properties of the glazing.

Comparison of the annual space heating loads of the basic house and the house with a heated or unheated glazed space

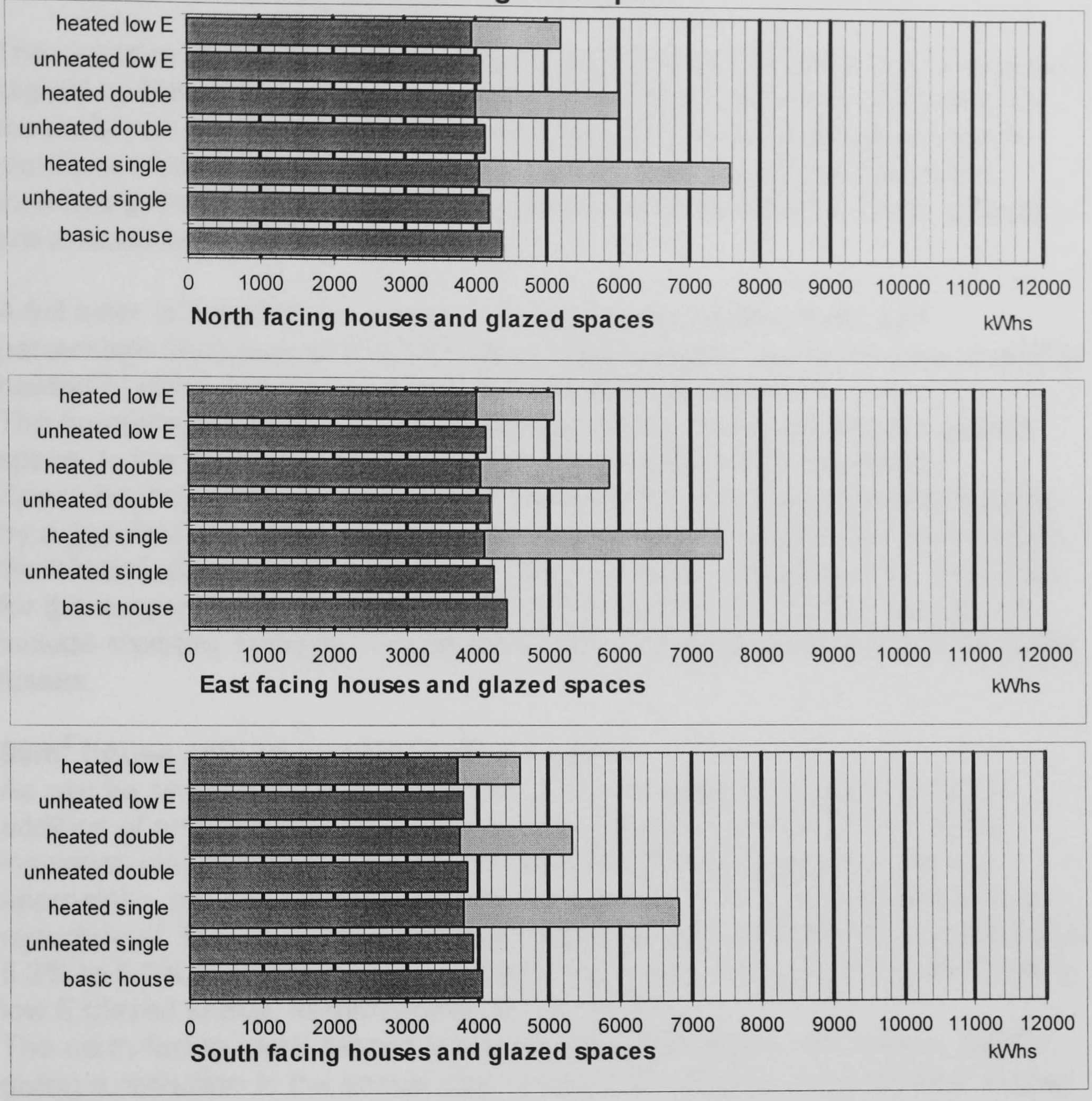


Figure 3.07 **Annual space heating loads for 90m^2 houses and attached single storey glazed spaces**

Conclusions which can be drawn from analysis of the predicted annual space heating loads

The charts in Figure 3.07 predict that the annual space heating load is reduced slightly by the presence of an unheated glazed space and reduced further by the presence of a heated glazed space. However, heating the glazed space results in a considerable increase in the total heating load, the size of the increase depending on the insulating properties of the glazing. These effects are discussed in greater detail below.

A full table of the simulation results, related space heating costs and percentage increases and reductions in heating loads, due to the presence of a heated or unheated glazed space, is included in Appendix G.
The percentage figures relate the heating load for the house with the glazed space, to the heating load for the basic house of the same orientation.
Space heating costs are based on the assumption that the house was heated by a gas fired, hot water radiator system and that this system was also used in the heated glazed spaces. The costs are calculated using the June 1995 price for the supply of gas, 1.54 pence per kWh [including VAT at 8%], but do not include standing charges. Neither the heating loads nor the costs include boiler losses.

90m^2 house with an unheated glazed space

As can be seen from the charts on the previous page and Appendix G the addition of an unheated single storey glazed space to a house, built to the insulation standards required by the 1995 Building Regulations, does not appreciably reduce the annual house heating load. The effect ranges from a reduction of 3.5% to 4.2% for a single glazed [double roof] space, a reduction of 5.2% to 5.5% for a double glazed space and a reduction of 6.4% to 6.8 % for a low E glazed space, all depending on orientation.
The north-facing low E glazed space provided the largest reduction of 6.82% giving a reduction in the annual cost of space heating for a typical 90m^2 house of only £4.50.
The south-facing single glazed space provided the smallest reduction of 3.49% giving a reduction in the annual cost of space heating of £2
As stated previously, the glazed space was operating in buffer mode, and no attempt was made to transfer warm air from the glazed space into the rooms of the house during the simulations.

90m^2 house with a heated glazed space

Heating the glazed space for five hours on weekdays and thirteen hours at weekends has a very great effect on the predicted annual house heating load for the single glazed [double roof] option. The increase, on the basic house heating load, ranges from 67.3% to 73.6% depending on orientation.
For a fully double glazed space the increase ranges from 31.0% to 37.6%, and for a low E glazed space the increase ranges from 13.6% to 19.1%, all depending on orientation.

Looking in greater depth at the extreme situations;

- for the **north facing single glazed space** [double roof], predicted annual space heating costs are as follows;

the basic house=£67
the house with an unheated glazed space=£64
the house with a heated glazed space=£117
[made up of £62 for the house and £55 for the glazed space]
The total figure of £117, represents an increase of 73.6% on the basic house figure or 81.3% on the figure for the house with an unheated glazed space

- for the **south facing low E glazed space**, predicted annual space heating costs are as follows;

the basic house =£63
the house with an unheated glazed space=£59
the house with a heated glazed space=£71
[made up of £57 for the house and £14 for the glazed space]
The total figure of £71, represents an increase of 13.6% on the basic house figure or 21.3% on the figure for the house with an unheated glazed space

The effect of the presence of the glazed space on overheating in the adjoining living rooms

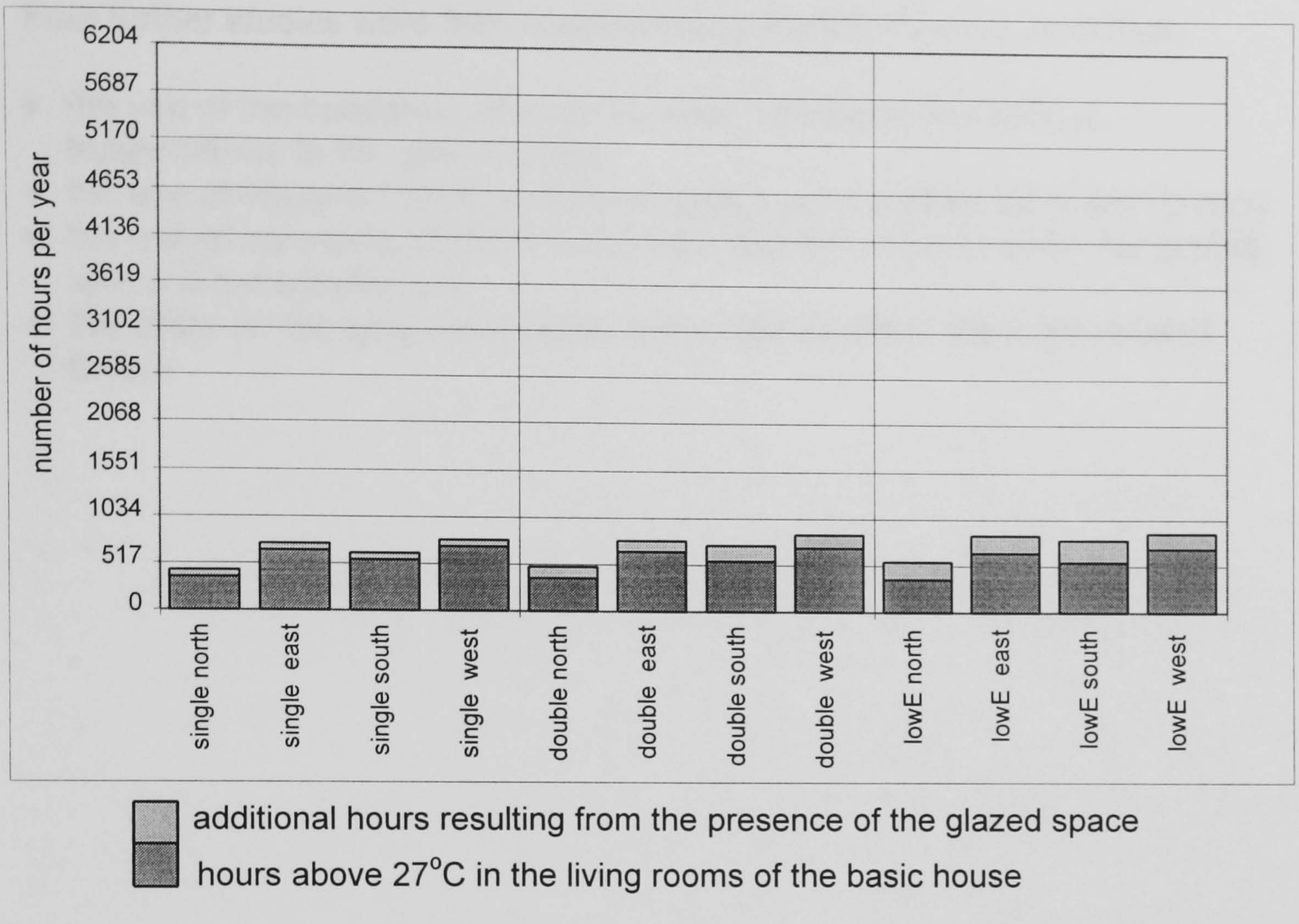


Figure 3.08 **The number of hours per year when the air temperature exceeds 27°C in the occupied living rooms**

The above chart gives the results of the checks on air temperatures in the living rooms. The temperatures were calculated hourly between 6.00 hours and 23.00 hours, [17 hours per day] for a year. The vertical axis represents one whole year and is divided into 12 nominal months [517 hours per month] and so gives a broad picture of the proportion of the year during which the living rooms would be uncomfortably hot, if all the hours when the temperature was higher than 27°C were consolidated.

The degree of overheating, attributable to solar gain, in the occupied rooms of a house depends to a great extent on the size and positioning of the windows. The chart above indicates that the living rooms of the basic houses with east and west orientations experience the highest number of hours when the air temperature exceeds 27°C. This is explained by the low morning and evening sun angles associated with these orientations.

Figure 3.08 shows that the addition of an unventilated glazed space to a house, of the design under study, will increase the overheating in adjoining rooms and that the degree of overheating will increase with increase in the insulating properties of the glazing to the glazed space, even allowing for the reduced transmission of solar radiation into the space. In the worst case, the addition of a south-facing, low E glazed space increased the consolidated period of overheating by approximately two weeks.

Further Studies

Four further studies were then undertaken on the 90m^2 model as follows;

- the use of the buoyancy effect to increase ventilation and reduce temperatures in the glazed space
- the use of insulated blinds to reduce energy consumption for space heating
- the use of insulating blinds to reduce the number of hours when the glazed space is too cold for use
- the effect of changing the location of the weatherfile to the north-west of Britain

3.04 The Use of the Buoyancy Effect to Increase Ventilation and Reduce High Temperatures in the Glazed Space

The strategy for the simulation of buoyancy driven ventilation described in Chapter 2.10 was applied to the single storey glazed space as described below.

The incorporation of high and low level ventilators into the glazed space
In order to determine the suitable size and position of ventilation openings the practical aspects of incorporating high and low level vents into the design of the single storey glazed space was investigated.
Doors and windows could be used for this purpose, though locking devices which limit the width of openings would need to be used to provide security.
Opening rooflights could provide the ventilation at the highest possible level, though maintaining a weathertight seal around the rooflight could be problematical, in view of the thermal stresses imposed on a glazed roof.
Internal or external blinds used to reduce glare on bright days could also create a problem in covering ventilation openings, particularly those in the roof.
Low level ventilation was therefore envisaged in the form of a row of air bricks at low level and glazed louvres or narrow opening lights at high level in the walls of the glazed space. In practice the air bricks would need to be backed by a shutter which could be hinged or slid up or down to block out unwanted draughts in colder months.
The CIBSE Guide, Section A4 [CIBSE,1986] gives a table of the open area which can be expected from different types of airbrick. The cast iron type, with square holes, of length 225mm and height, 75mm provide 0.0072 m^2 of open area and those of length 225mm and height, 150mm, provide 0.0127m^2 .
It was calculated that 24 of the former could provide a total of at least 0.15 m^2 of open area and the latter at least 0.3m^2 of open area. The incorporation of the airbricks and the high level openings, into the design of the glazed space is shown overleaf in Figure 3.09.

The iterative process and one day simulation
The south facing low E glazed model was used for this investigation as the initial simulations indicated that this combination of orientation and glazing provided the lowest number of comfortable hours during June, July and August.
The strategy for the simulation of buoyancy driven ventilation was worked through twice using the alternative areas for high and low level openings; 0.15m^2 and 0.3m^2.
The day chosen from the weatherfile for the test simulations was day 201, July 20th, see Appendix F. The day is generally cloudy with predominantly diffuse solar radiation but with short periods of direct solar radiation during hours 5-9 and hour 16. This was one of the coolest days of the month and so the ultimate air change rates, predicted in the simulation results, would be minimum levels which could be expected to be exceeded on days of higher levels of direct and

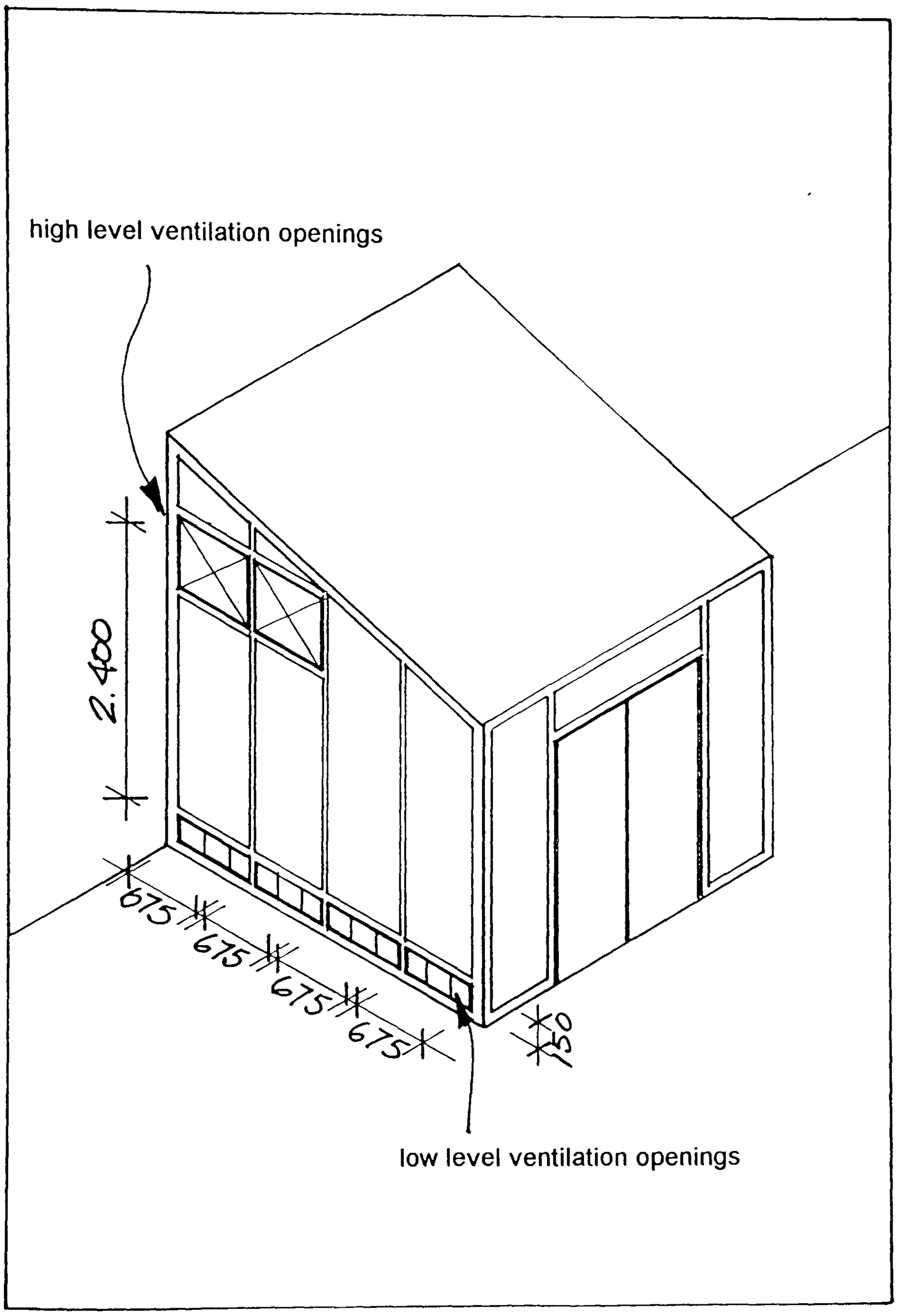


Figure 3.09 **The incorporation of high and low level ventilation openings into the single storey glazed space**

diffuse solar radiation. In a glazed space the internal temperature is elevated to such a level above external air temperature, by the effect of solar radiation, that the temperature differences assumed in the method could be expected to be maintained, even on days of high external air temperature.
This assumption was checked by repeating the iteration process for day 180, June 29th, see Appendix F. The day experiences bright sunshine from hours 7.00 -15.00hrs [GMT] with external air temperature reaching a peak of 20.2°C in the late afternoon.
As can be seen from Table 3.03 below, similar or higher air change rates are promoted on Day 180 than on Day 201. This is due to the larger internal / external air temperature difference occurring on Day 180. Although the external air temperature is higher for Day 180, the internal temperature is raised even more due to the effect of higher levels of solar gain in the glazed space.

Table 3.03 **The air change rates achieved at the end of the iterative process for Day 201 and Day 180**

	0.15m² openings at high and low level		0.3m² openings at high and low level	
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h
0.00-8.00hrs	7.8	7.9	10.3	13.4
8.00-1200hrs	9.8	12.6	17.0	21.7
12.00-16.00hrs	9.8	12.8	17.0	22.0
16.00hrs-20.00hrs	7.8	9.5	13.3	15.9
20.00-24.00hrs	7.8	7.7	13.3	12.7

Analysis of the results for Day 201
The one day simulation results for internal air temperature and resultant temperature, on Day 201, using the above Day 201 air change rates, are shown in Figures 3.10 and 3.11 overleaf, for the two areas for the openings. The external air temperature and the internal air temperature and resultant temperature at the start of the process when the ventilation openings were closed [infiltration 0.85 ac/h] are also include in the charts for comparison.
Looking firstly at the initial temperatures, with the ventilators closed, the charts show clearly the effect of the diffuse and short periods of direct solar radiation on the air and resultant temperatures within the glazed space. The initial resultant temperature reached a maximum value of 39.5°C and the initial internal air temperature reached a maximum value of 36.3 °C.
Openings of 0.15m² , at both high and low level, reduced these to 31.5°C and 25.6°C respectively and openings of 0.3m² , at both high and low level, reduced the values to 29.4°C and 22.7°C respectively
Although the air temperatures were much reduced by the effect of the increased air change rates, the effect on the resultant temperatures were less marked due to the radiant temperatures of the surfaces which remained high.

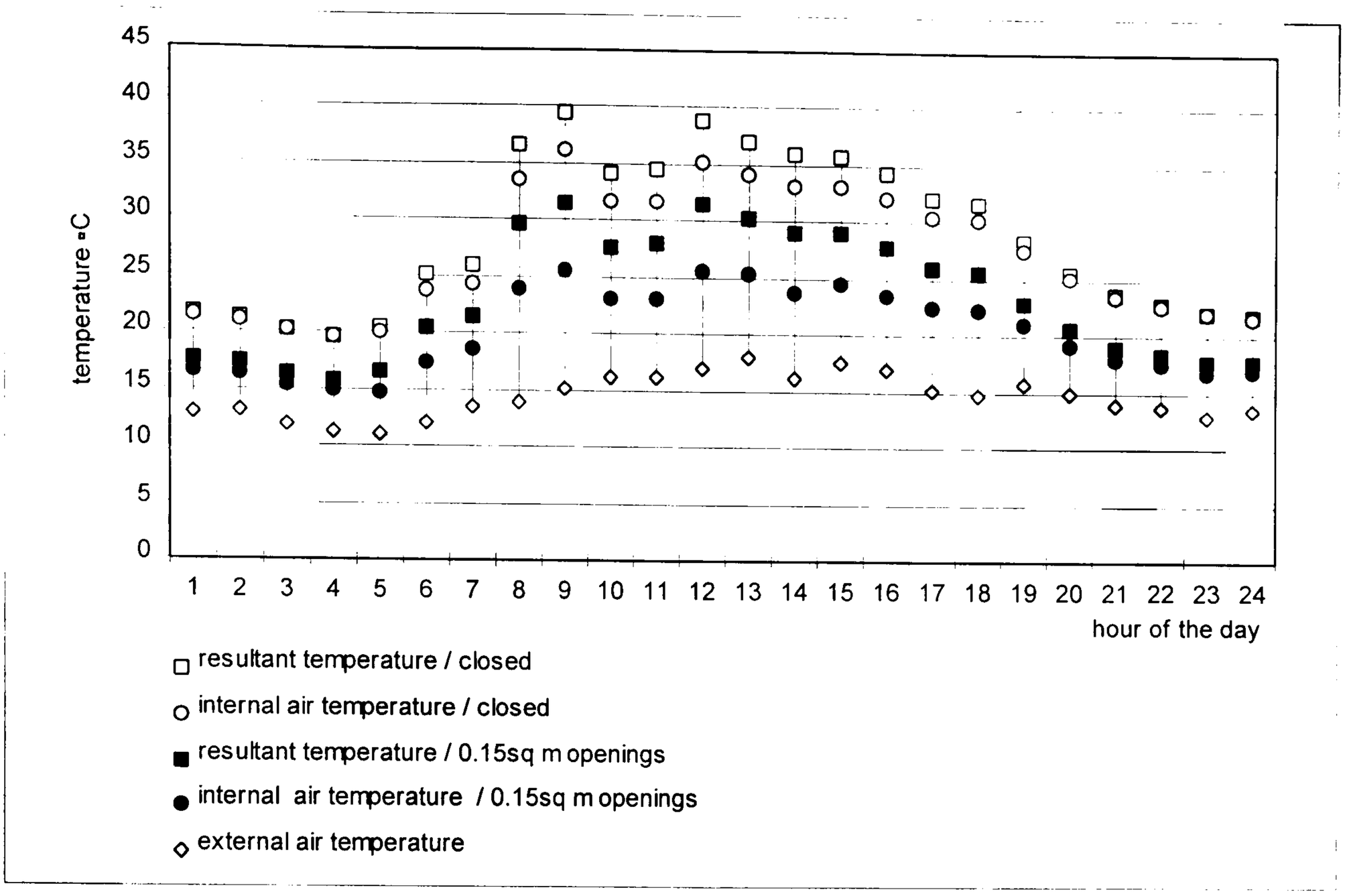


Figure 3.10 **Temperature reduction caused by openings of area, 0.15 m^2 in the south facing, single storey low E glazed space, Day 201**

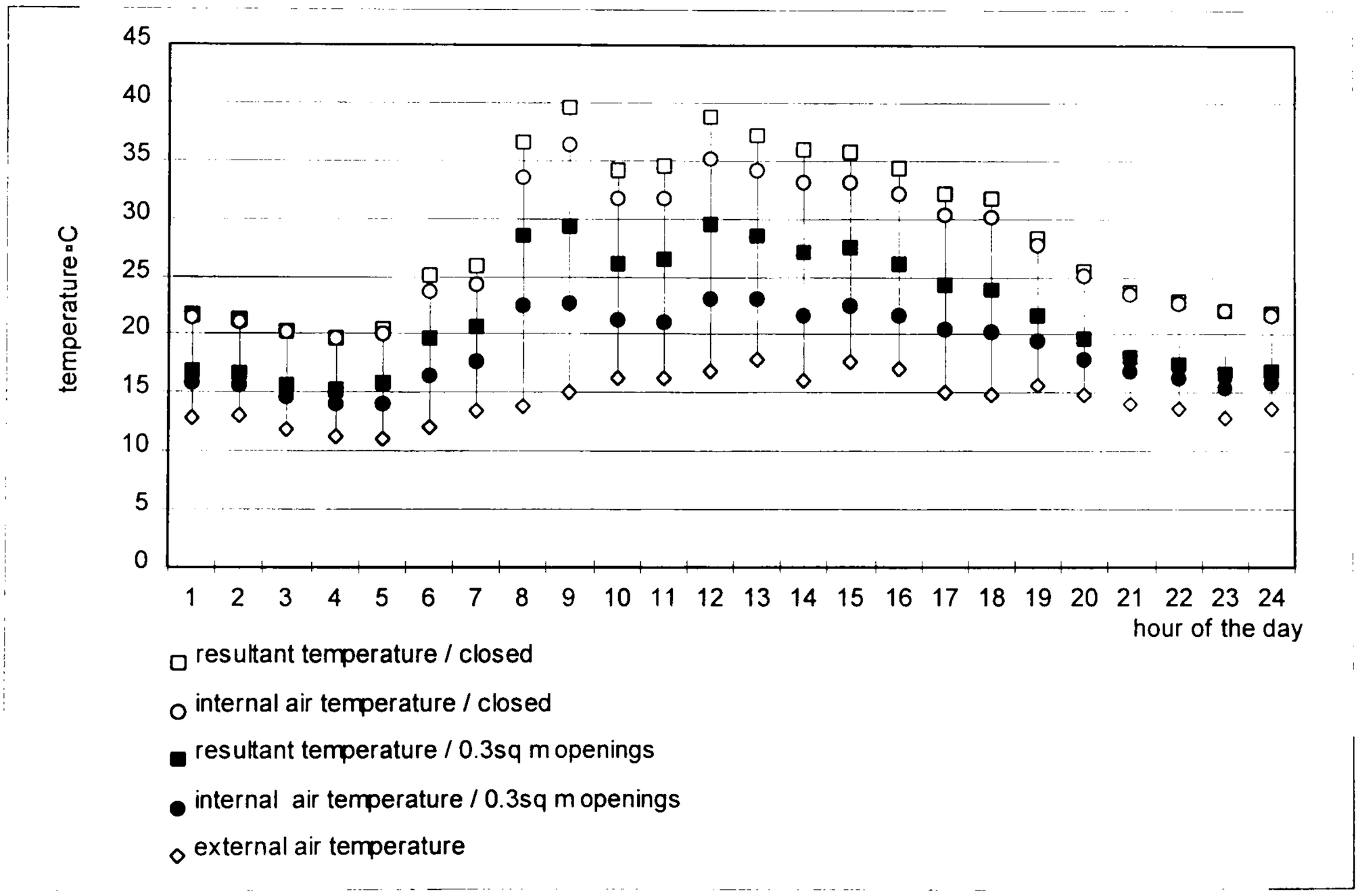


Figure 3.11 **Temperature reduction caused by openings of area, 0.3 m^2 in the south facing, single storey, low E glazed space, Day 201**

Analysis of the results for Day 180

The one day simulation results for internal air temperature and resultant temperature, on Day 180, using the Day 180 air change rates, are shown in Figures 3.12 and 3.13, below and overleaf, for the two areas for the openings. The external air temperature and the internal air temperature and resultant temperature at the start of the process when the ventilation openings were closed [infiltration 0.85 ac/h] are also include in the charts for comparison. Looking firstly at the initial temperatures, with ventilators closed, the charts again show clearly the effect of the direct solar radiation on the air and resultant temperatures within the glazed space. The initial resultant temperature reached a maximum value of 57.6°C and the initial internal air temperature reached a maximum value of 53.6 °C, even though the external air temperature only reached a maximum of 20.2°C

Openings of 0.15m^2 , at both high and low levels, reduced these to 43.2°C and 34.5°C respectively. Although the temperatures are much reduced by the effect of the increased air change rates, for 0.15 m^2 openings, the reduction of resultant temperatures to levels below 27°C is only achieved during the evening, though this usable period would be appreciated. [hours from midnight to 7.00hrs. not considered for use]

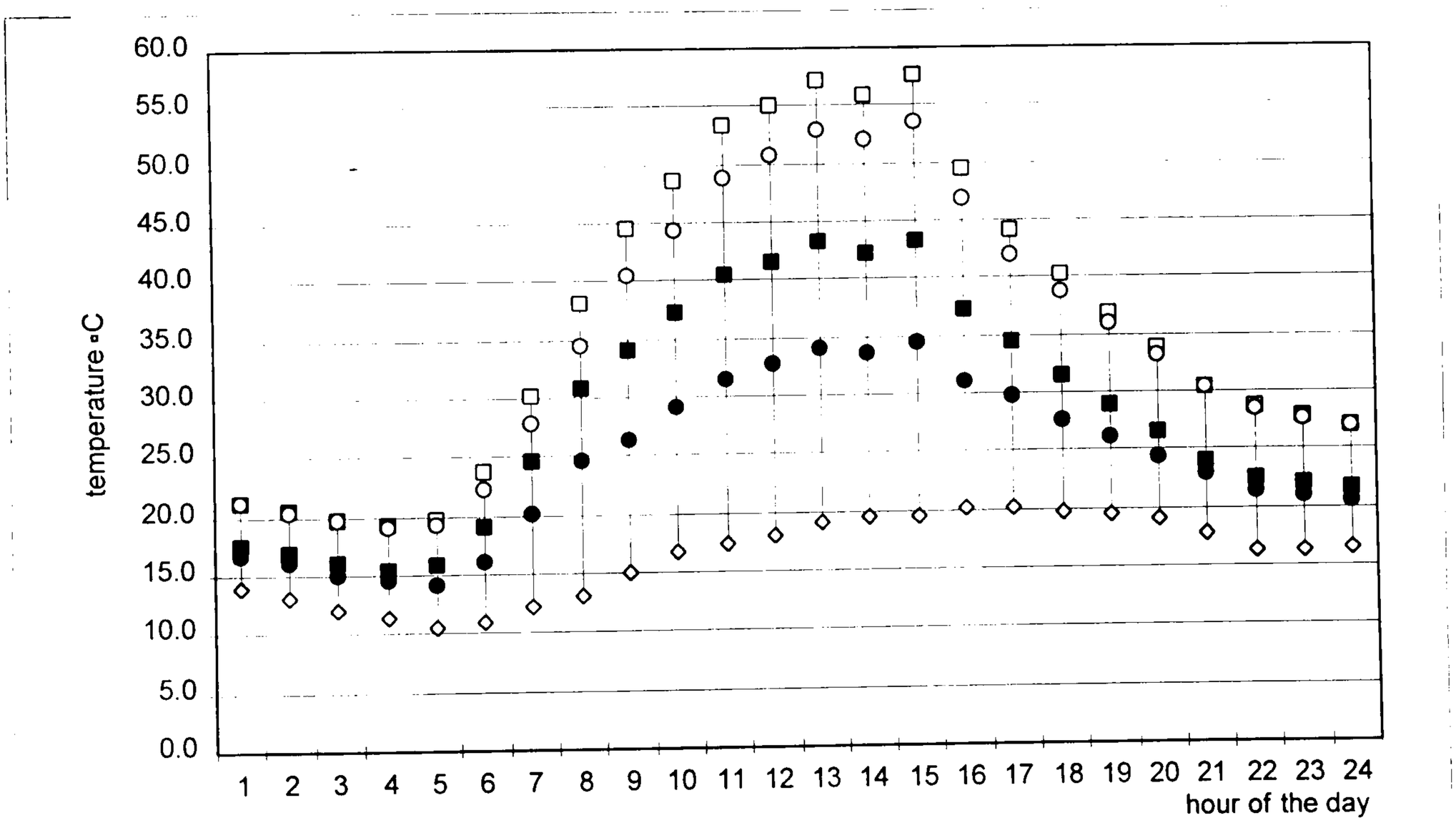


Figure 3.12 **Temperature reduction caused by openings of area, 0.15 m^2 in the south facing, single storey low E glazed space, Day 180**

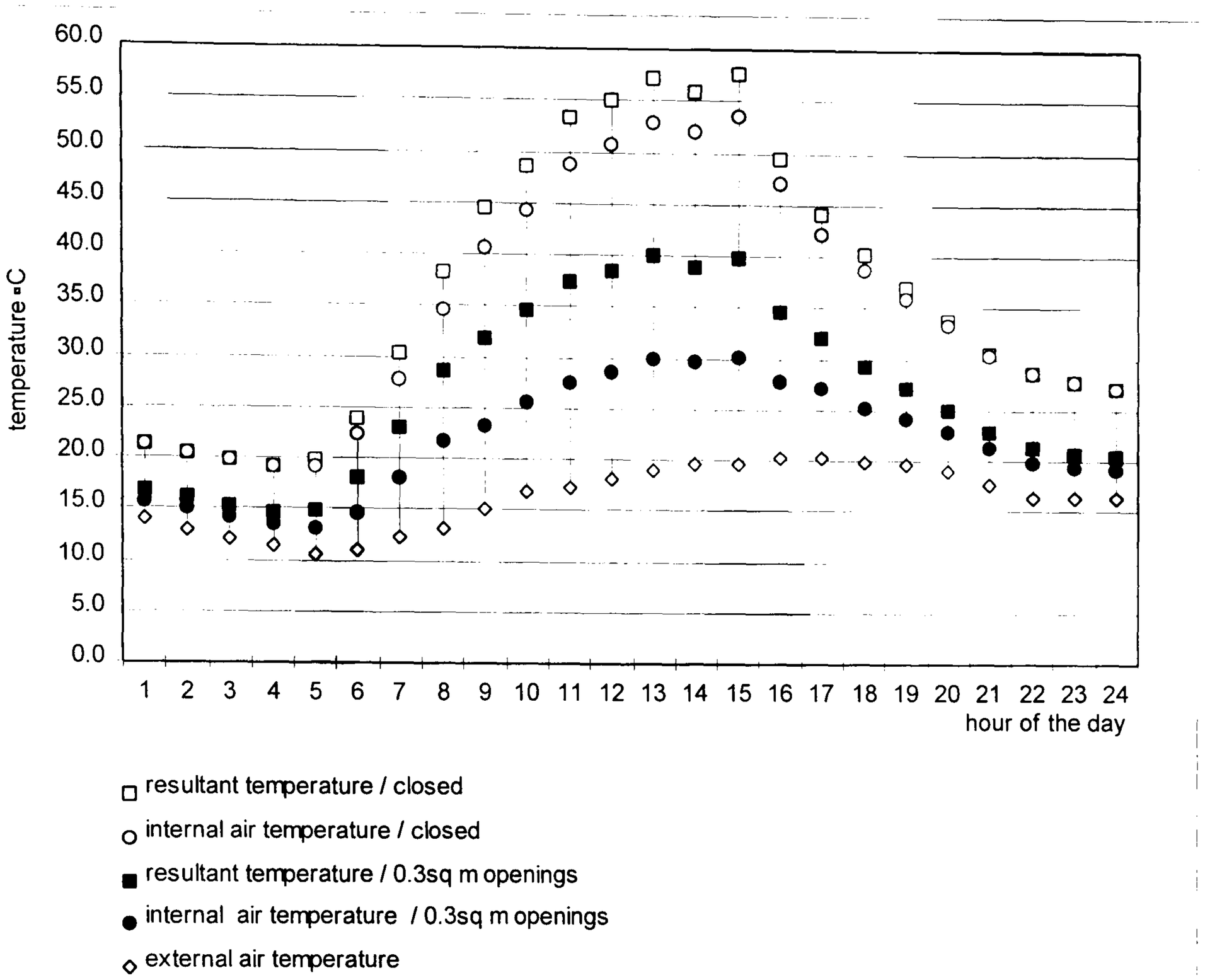


Figure 3.13 **Temperature reduction caused by openings of area, 0.3m^2 in the south facing, single storey, low E glazed space, Day 180**

As shown in Figure 3.13 openings of 0.3m^2, at both high and low level, reduced the peak resultant temperature to 39.9°C and the peak air temperature to 30.2°C.
Although the temperatures are much reduced the usable hours below 27°C again occur only in the evening period.

Estimating the effect of bouancy driven ventilation during July

In order to investigate the possible effect of boyancy driven ventilation occurring over a longer period than one day, the figures for the air change rates obtained for Day 201, were put into the internal conditions data sheet for the glazed space for the whole of the month of July and the thermal simulation re-run for the year. The hours for resultant temperatures above 30°C and 27°C and below 16°C and 12°C were obtained from the simulation results via the report generator program. Figure 3.14 overleaf illustrates the results for the July period together with a chart of the results of the initial simulation, [ventilators closed] for comparison.
The charts indicate a substantial reduction in the hours of overheating in July, brought about by the ventilation strategy. The reduction resulting from the 0.15m^2 ventilation openings being greater than the additional reduction

resulting from the increase of this area to 0.3m^2. Over half of the available hours during July still remained uncomfortable due to high temperatures. 77% of the evening hours, 119 out of a maximum of 155 fell within the comfortable resultant temperature range.
However, Day 201 was a mainly overcast day and higher air change rates could be expected on days of bright sunshine, as indicated by the simulations for Day 180. In reality therefore the number of comfortable hours in July could possibly be higher than those indicated below. The simulations for the two days and for the month of July indicate the possibilities for controlling high temperatures in glazed spaces by the use of bouyancy driven ventilation. For conclusive evidence of the effect over the month of July, the iterative process would have to be repeated so as to obtain estimates of the air change rates and their effect on the resultant temperatures for each specific day Unfortunately the process of manual iteration is time consuming and it is not possible within the scope of this study to repeat the procedure to such an extent.

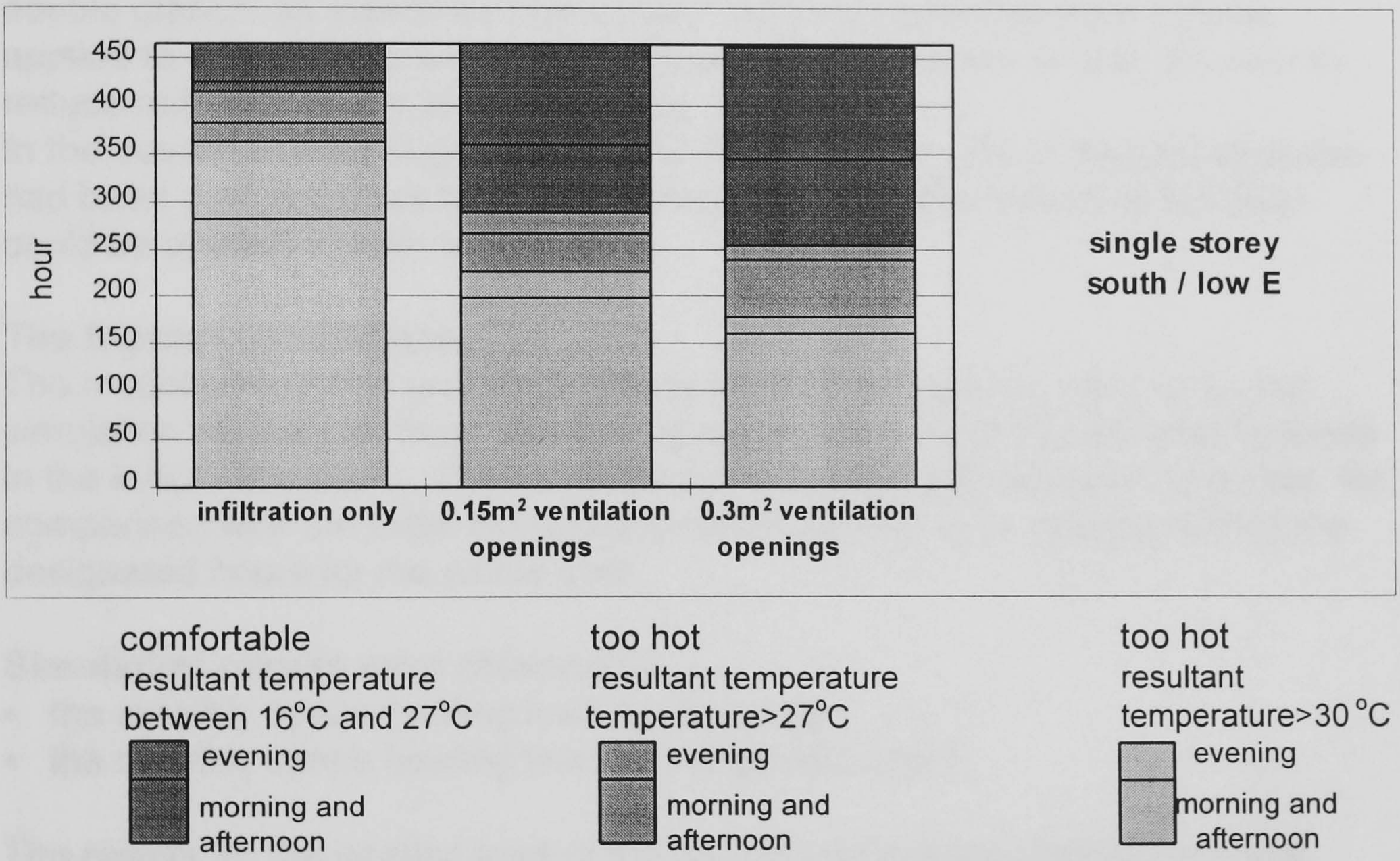


Figure 3.14 **The effect of increasing ventilation rates during July in a single storey, south facing, low E glazed space**

Appendix F contains a chart of the south-east weatherfile showing that the ambient temperature, does not rise above 27°C during the month of July. Figure 3.14 above indicates the problems caused by inadequate ventilation [infiltration only], the resultant temperature, between 8.00 and 23.00hrs, is above 30°C for a large proportion of the month even though ambient temperatures are not extreme.

3.05 The Use of Insulating Blinds to Reduce the Heating Load for the Glazed Space

In an attempt to reduce the annual heating load of the heated glazed spaces a theoretical insulating blind material, as described in Chapter 2.08 on Building Constructions, was devised and incorporated into the appropriate models.

Application of the insulating blind to the models
The Tas software provides a 'shutter' facility which allows an alternative construction to be substituted into the simulation process, for one building element, at times of day entered by the operator, thus representing the opening and closing of blinds and shutters. In this case the blinds were programmed to close at 17.00 hours and open at 8.00 hours
The walls and the roof of the 'single glazed' model had been designated as separate building elements as the walls were single glazed and the roof was double glazed, as explained previously. The blind could therefore only be applied to one of these elements and the roof was chosen for this, in order to reduce radiative losses to the night sky.
In the double and low E glazed models, the roof and walls of the glazed space had been designated as the same 'glazing' element and therefore the blind could be applied to both situations.

The thermal simulations
The models with north and south facing glazed spaces were chosen for the simulation process as they had the highest and lowest predicted heating loads in the initial simulations. The models were simulated over a period of a year, for comparison with the initial simulations and the blinds were in place during the designated hours for the whole year.

Simulation results were obtained for;
- the monthly space heating load for the house
- the monthly space heating load for the glazed space

The results for the heating load of the glazed space are presented overleaf, together with the results of the initial simulations for the same models for comparison.
The results of the simulations and the related space heating costs are also presented in Appendix G.

Discussion of the simulation results
The results and the charts indicate that the addition of an insulating blind to the roof of the single glazed model makes very little difference to the annual space heating load of the glazed space. A reduction of approximately £3 in the annual cost of space heating is indicated for both orientations.

The addition of insulating blinds to the walls and roof of the double glazed model reduces the annual space heating load for the glazed space almost to that of the low E glazed space for both north and south orientations.
The addition of a blind to the low E glazed spaces reduces the heating load for the glazed spaces by approximately £5 resulting in an annual space heating load for the north facing space of £14.28 and for the south facing space of £9.44. As the presence of the insulating blind, maintains higher temperatures in the glazed spaces, this in turn reduces heat loss from the living rooms thus reducing the annual space heating load for the house.

This gives the following figures for annual space heating loads;
north facing basic house = £67.30
north facing house + heated low E glazed space with insulating blind =£74.35
south facing basic house =£62.55
south facing house + heated low E glazed space with insulating blind =£65.68

- with insulating blinds to the roof and walls of the double glazed and low E models and to the roof of the single glazed model [double glazed roof]
- without insulating blinds -results from the initial simulations

Figure 3.15 **Annual space heating loads for glazed spaces with and without insulating blinds**

The predictions for the double and low E glazed models are encouraging in terms of the possibilities for reducing energy usage in glazed spaces. However the blind material included in the thermal models was only a theoretical solution. In the thermal model the blinds form a continuous layer whereas in practice there would be joints at corners and between sheets through which heat loss would occur. Also, in practice the use of a similar material on the inside of the glazing could lead to the formation of condensation on the glazing and framing members which would in turn result in a reduction in the insulating properties and deterioration of the frames.
In order to avoid the condensation problem the insulation material could be used to form an external blind, but would need to run between substantial guides to avoid wind damage. Automatic control from within the glazed space would also be needed to ensure use of the blind.

For the simulations, the blinds were closed at 17.00hrs and opened at 8.00hrs The simulation results showed that heating was required in the glazed spaces from October to March/April. Closure of the blinds at the specified times could be acceptable in practice as there is little daylight to be enjoyed in the evenings during these months. However the closure of the blinds and the consequent reduction of energy usage would depend entirely on the owners.

3.06 The Use of Insulating Blinds to Reduce the Number of Hours When the Glazed Space is Too Cold for Use

The insulating blind, described previously, was added to the roof and walls of the unheated south facing low E glazed model, between 17.00hrs and 8.00hrs and a thermal simulation performed for a years duration. The predicted hours when the temperature exceeded 16°C were substituted into the simulation results for the original model, for the months from October to March as shown below. When compared with the initial results, Figure 3.05 the chart below indicates that the number of uncomfortably cold hours would be reduced during March and October by approximately 50 hours. The effect during February and November is less marked and during January and December there is little change. This suggests that for other orientations particularly north and east and glazing with lower insulating properties, the addition of an insulating blind would have little effect in increasing the number of hours when the temperature exceeded 16°C.

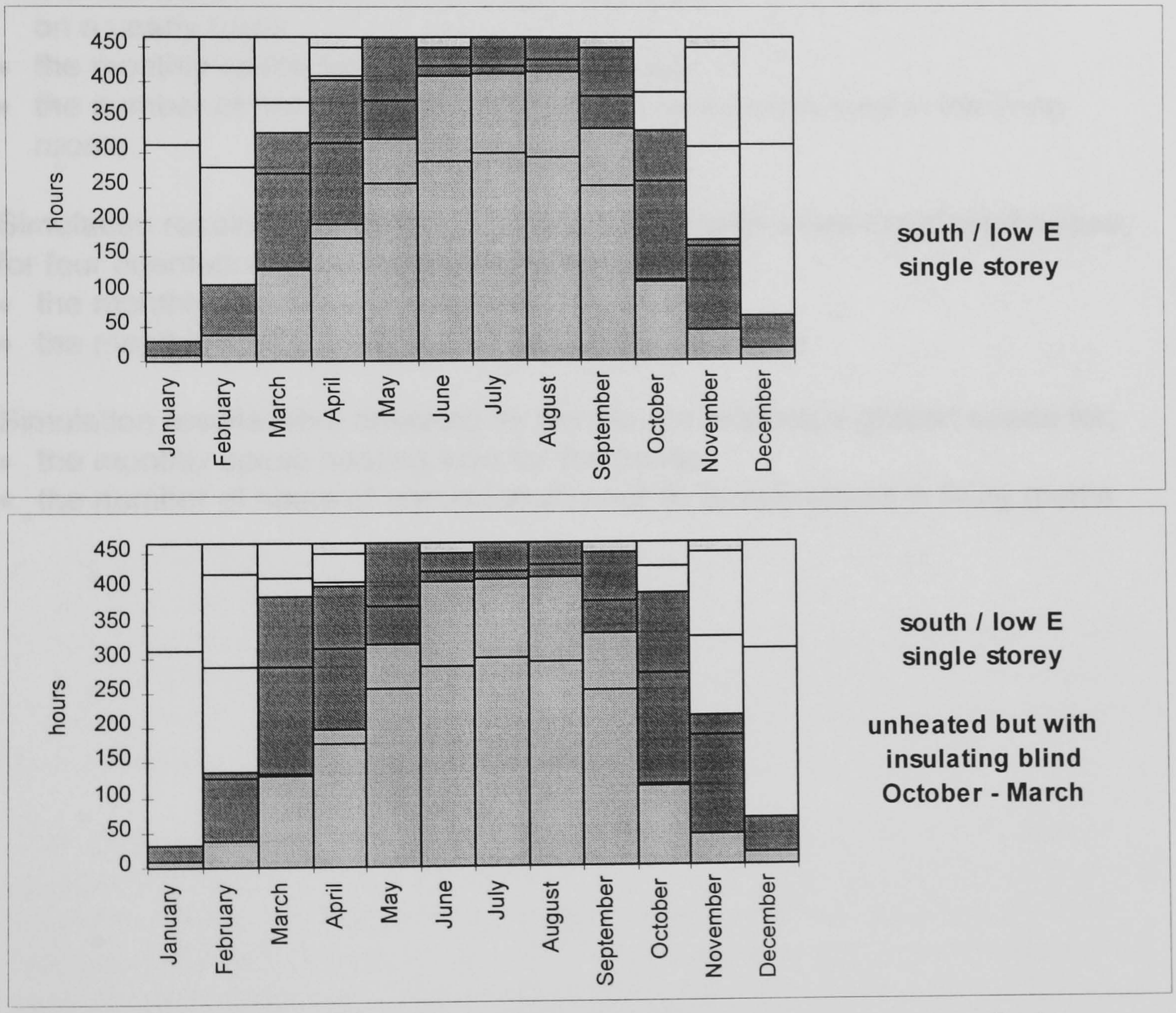


Figure 3.16 **Resultant temperatures in the south facing low E glazed space without and with an insulating blind**

3.07 The Effect of Changing the Location of the Weatherfile to the North-west of Britain

The latitude of all the models was changed to 54.6° and the shadow calculations program re-run.
Thermal simulations were then performed for all the models using the weatherfile for the north-west of Britain.
Air infiltration into the glazed spaces was limited to the infiltration through the building fabric as in the initial simulations using the south-east weatherfile.

Simulation results
Simulation results were obtained for **the house with an unheated glazed space**, for four orientations and three glazing types for;

- the number of hours of comfortable temperatures in the glazed space, on a yearly basis
- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in the living rooms

Simulation results were obtained for **the house with a heated glazed space,** for four orientations and three glazing types for;

- the monthly space heating load for the house
- the monthly space heating load for the glazed space

Simulation results were obtained for **the house without a glazed space** for;

- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in living rooms

Comparison of the number of comfortable hours in the unheated glazed spaces, situated in north-west Britain, on a yearly basis

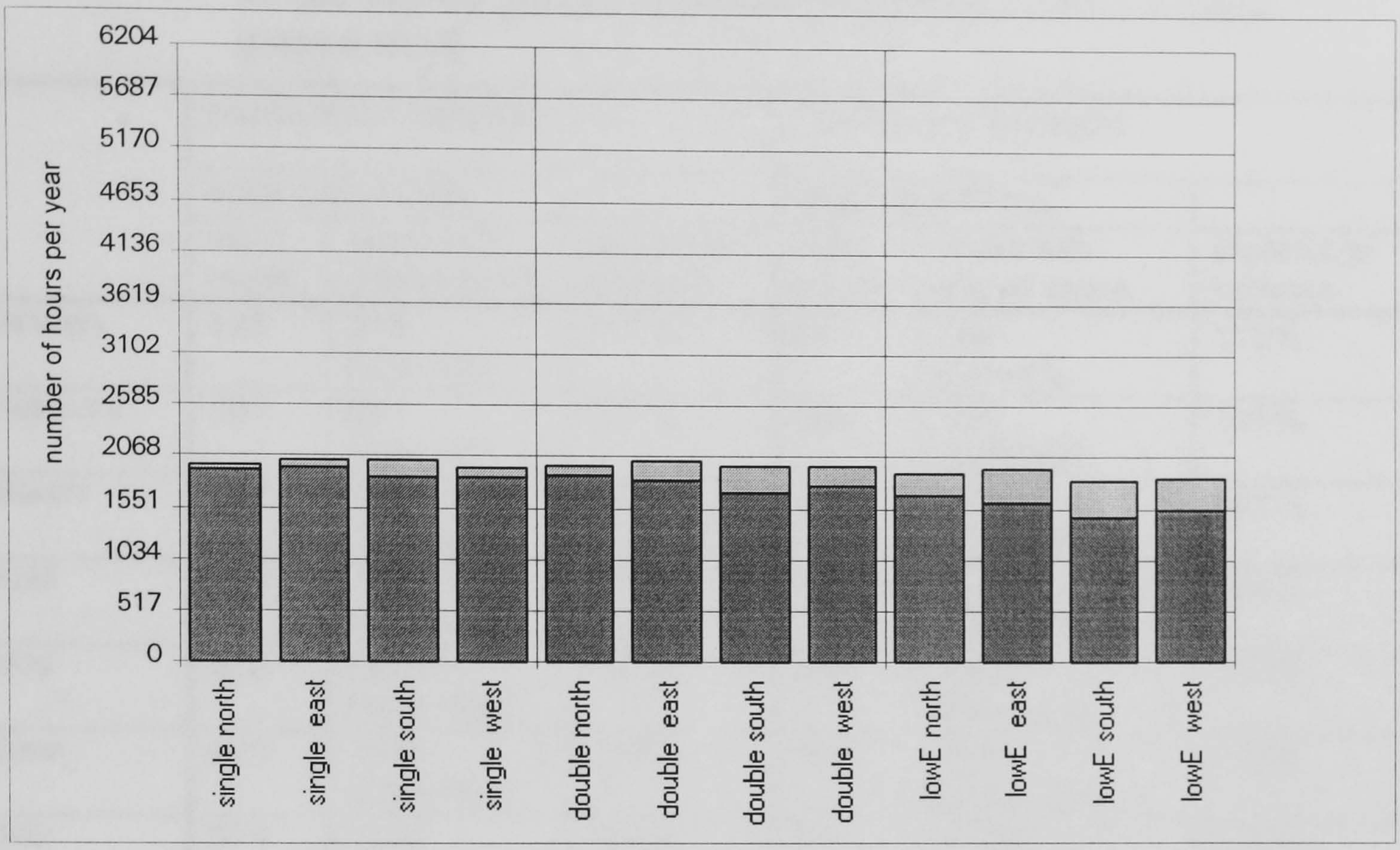


Figure 3.17 **The number of comfortable hours in the unheated glazed spaces using the north-west weatherfile**

The above chart indicates that in an unheated, unventilated mode;

- the glazed spaces are only usable for 29% to 33% of the year or approximately $3^1/_2$ - 4 months.
- In comparison with the results for glazed spaces in the south-east of Britain, Figure 3.02, there are fewer usable hours during the Greenwich Meantime period but more during British Summertime, resulting in a greater number of comfortable hours overall, for each glazing type and orientation.

The Table 3.04 overleaf lists the solar gain experienced in the south-facing basic house and the south facing house with single glazed space in both south-east and north-west locations, as predicted by the thermal simulations. The houses and glazed spaces in the north-west location experienced lower levels of solar gain than those in the south-east location for most months of the year. This to some extent explains the higher number of comfortable hours during the British Summertime experienced in the north-west location. Ambient temperatures in the north-west are in general lower than those experienced in the south-east as indicated by the climate data listed in Appendix F, this also contributes to the higher number of comfortable hours experienced in the glazed spaces located in the north-west.

Table 3.04 **Predicted solar gain experienced in the two locations for the south facing basic house and the south-facing house with a single storey glazed space [single glazed walls, double glazed roof]**

	south-east location			north-west location		
	solar gain kWhs			solar gain kWhs		
	basic house	house with glazed space	percentage increase	basic house	house with glazed space	percentage increase
January	146	318 [128+190]	117%	89	192 [79+113]	115%
February	291	661 [256+406]	127%	359	794 [312+482]	121%
March	522	1291 [464+827]	147%	409	987 [623+623]	141%
April	525	1419 [475+944]	170%	572	1510 [516+994]	164%
May	576	1623 [531+1092]	182%	504	1397 [464+933]	177%
June	625	1945 [573+1372]	211%	550	1519 [510+1009]	176%
July	574	1632 [530+1102]	184%	542	1476 [502+974]	172%
August	606	1703 [551+1152]	181%	470	1265 [429+836]	170%
September	601	1553 [532+1021]	158%	381	947 [341+606]	149%
October	398	915 [349+566]	130%	267	619 [237+382]	131%
November	330	703 [284+419]	113%	236	493 [204+289]	109%
December	221	458 [190+268]	107%	88	189 [79+110]	114%
Total	5415	14221 [4862+9359]	162%	4468	11389 [4038+7351]	154%

The percentage increase in solar gain for each location relates the solar gain experienced by the house with a glazed space to that experienced by the same house without a glazed space.
The figures in parenthesis indicate the predicted amount of solar gain received in zones 2,3 and 4 totalled separately from those received in the glazed space. For June in the north-west location, it can be seen that the glazed space experiences almost twice as much solar gain, 1009kWhs, as the other rooms combined, 510 kWhs , and more than twice as much, 1372 kWhs compared to 573 kWhs, in the south-east location.

Comparison of the annual space heating loads of the basic house and the house with a heated or unheated glazed space

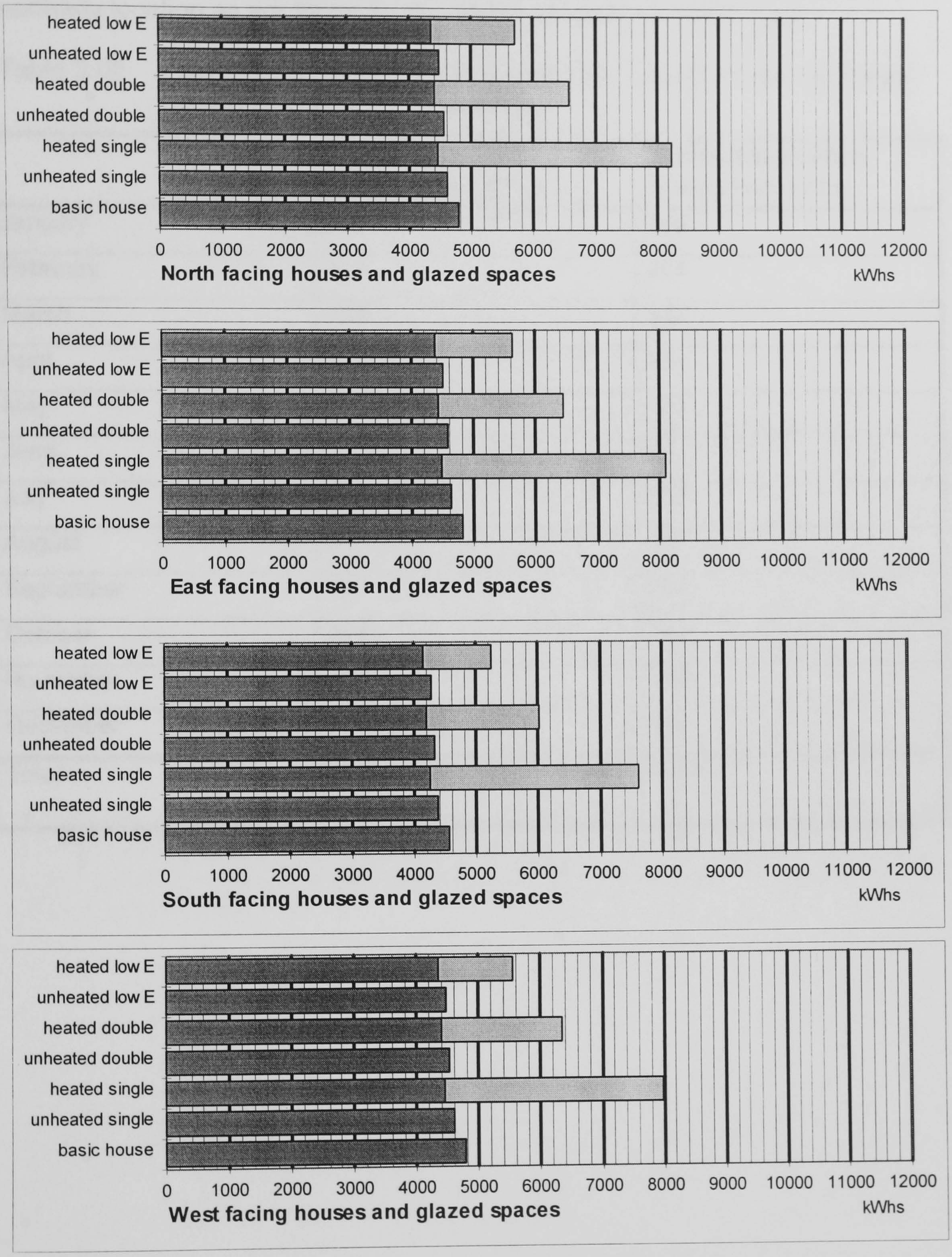


Figure 3.18 **Annual space heating loads for 90m^2 houses and attached single storey glazed spaces, using the north west weatherfile**

As can be seen by comparison of Figure 3.17 with Figure 3.07, for the south-east situation, the heating loads for the basic houses are higher in the more northerly location as are those for the glazed spaces, as listed below.

Table 3.05 **Predicted monthly heating loads for the south-facing single glazed spaces in two locations**

	south-east location heating load kWhs	north-west location heating load kWhs
January	573	576
February	471	454
March	328	323
April	239	251
May	69	127
June	5	17
July	9	14
August	5	31
September	49	110
October	261	307
November	440	499
December	578	654
Total	3027	3364

The effect of the presence of the glazed space on overheating in the adjoining living rooms

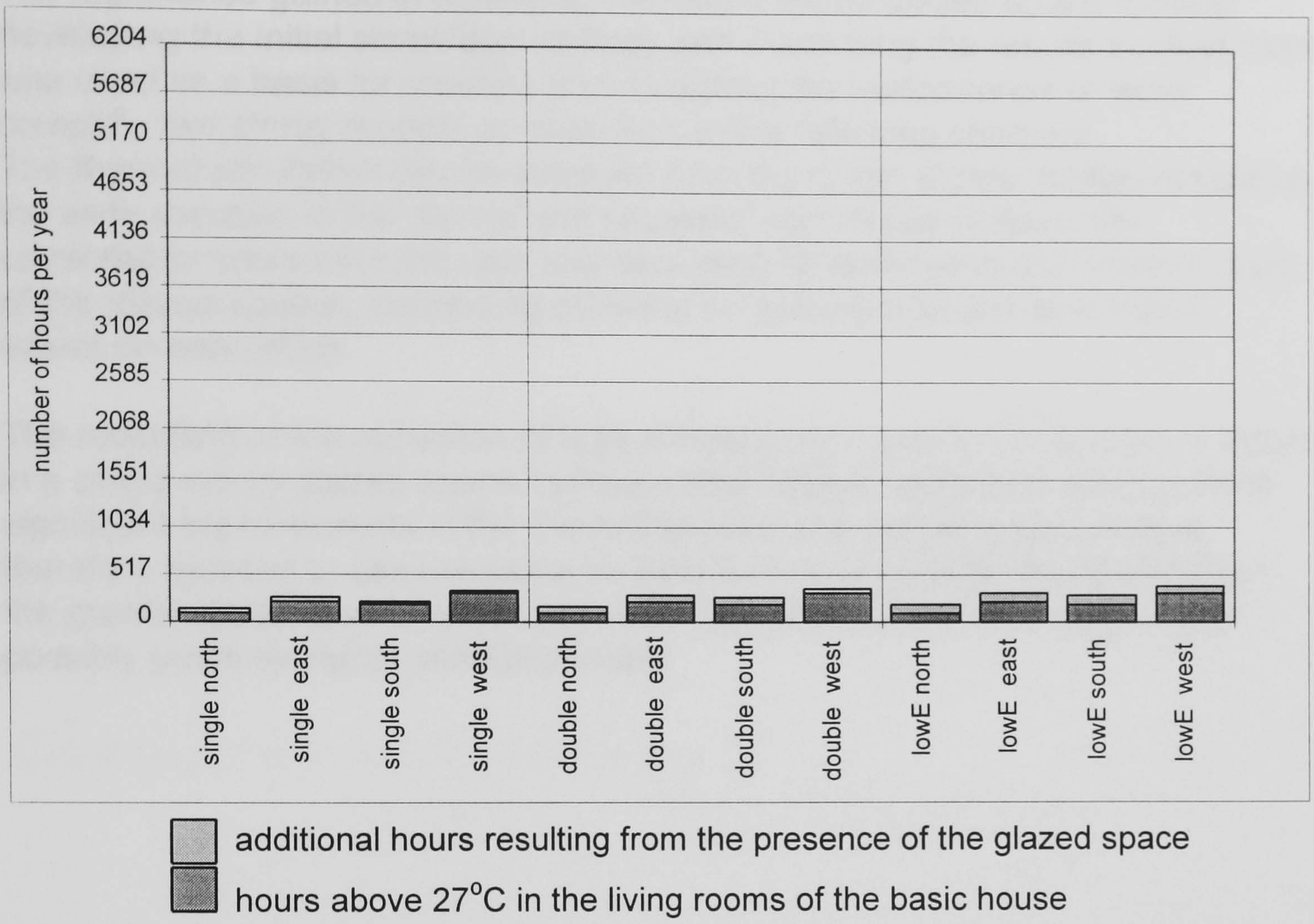


Figure 3.19 **The number of hours per year when the air temperature exceeds 27°C in the living rooms, north-west weatherfile**

As can be seen from comparison with Figure 3.08 the amount of overheating in a house in the north-west of Britain is considerably less than that experienced in the south-east and overheating in adjoining rooms due to the presence of the glazed space is also less.

3.08 Conclusions on the studies of the single storey glazed spaces

The experience gained in setting up the single storey glazed space models, developing the initial simulation strategy and presenting the results in chart form was used as a basis for creating and modelling the performance of more complex, two storey models as described in the following chapters.
The thermal simulation results obtained from the single storey models indicated the wide variation in the diurnal and seasonal occurrence of thermally comfortable hours over the year and also large differences in the heating loads of the glazed spaces, depending primarily on glazing type and to a lesser extent on orientation.

The modelling of the reduction of high temperatures, due to the buoyancy effect in a single storey glazed space indicated that natural ventilation could provide significant improvements in the thermal comfort in a glazed space. It was therefore decided to use the same method for the two storey spaces in which the greater distance achievable between high and low level openings could possibly promote higher ventilation rates.

CHAPTER 4

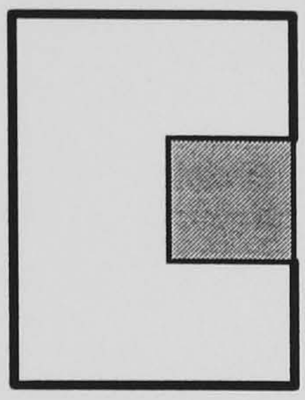
The Second Set of Thermal Models, Based on a Two Storey Glazed Space

4.01 Description of the Models

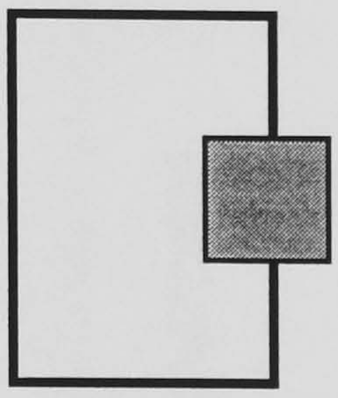
The second set of thermal models consisted of a series of two storey glazed spaces arranged in different configurations with a detached house. The basic house was larger in floor area than that used for the first set of thermal models, 110m^2 internal floor area, rather than 90m^2. This larger floor area allowed the accommodation to be arranged around an integral glazed space.

Three different models were set up with three different relationships between the two storey glazed space and the house;

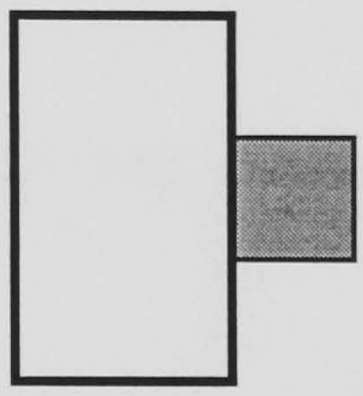
- relationships on plan



Integral



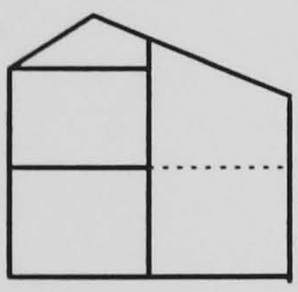
Semi-exposed



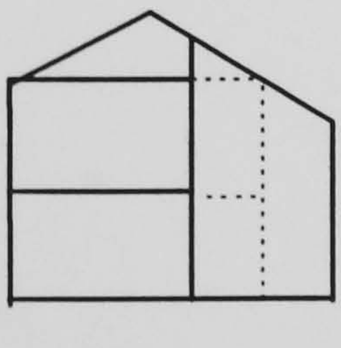
Exposed

- relationships in cross-section

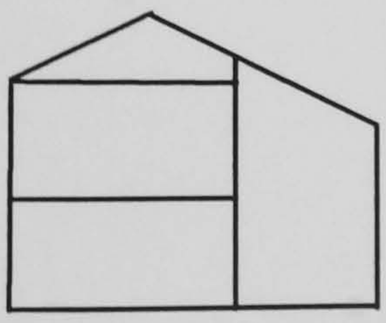
the houses were designed such that the three-dimensional form of the glazed space remained exactly the same in each case. This was achieved by adjusting the depth and the roof pitch of the basic house as shown below;



Integral glazed space
Bedrooms alongside the glazed space have sloping ceilings to maintain a constant volume
..... represents the upper floors in the surrounding rooms



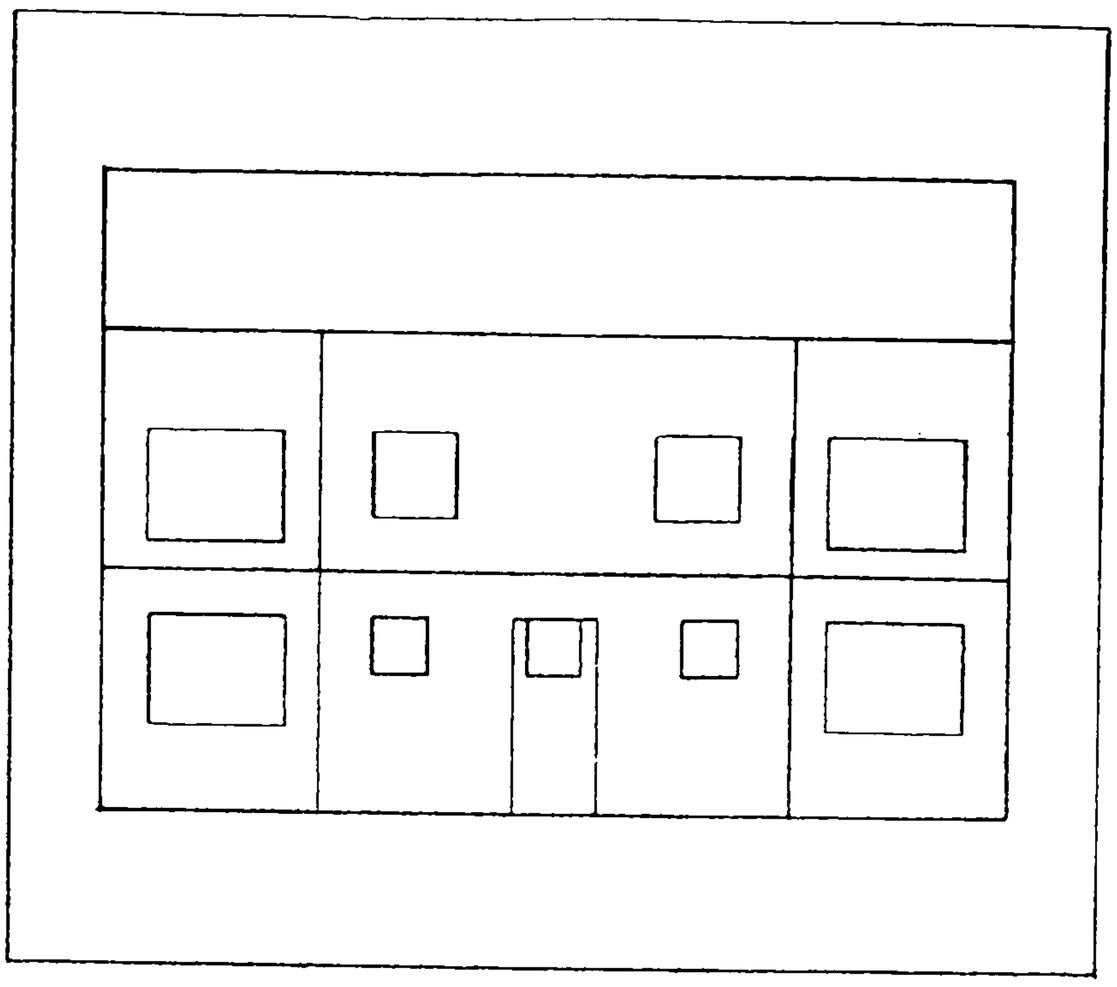
Semi-exposed glazed space
..... represents the floors, ceilings and external walls of the surrounding rooms



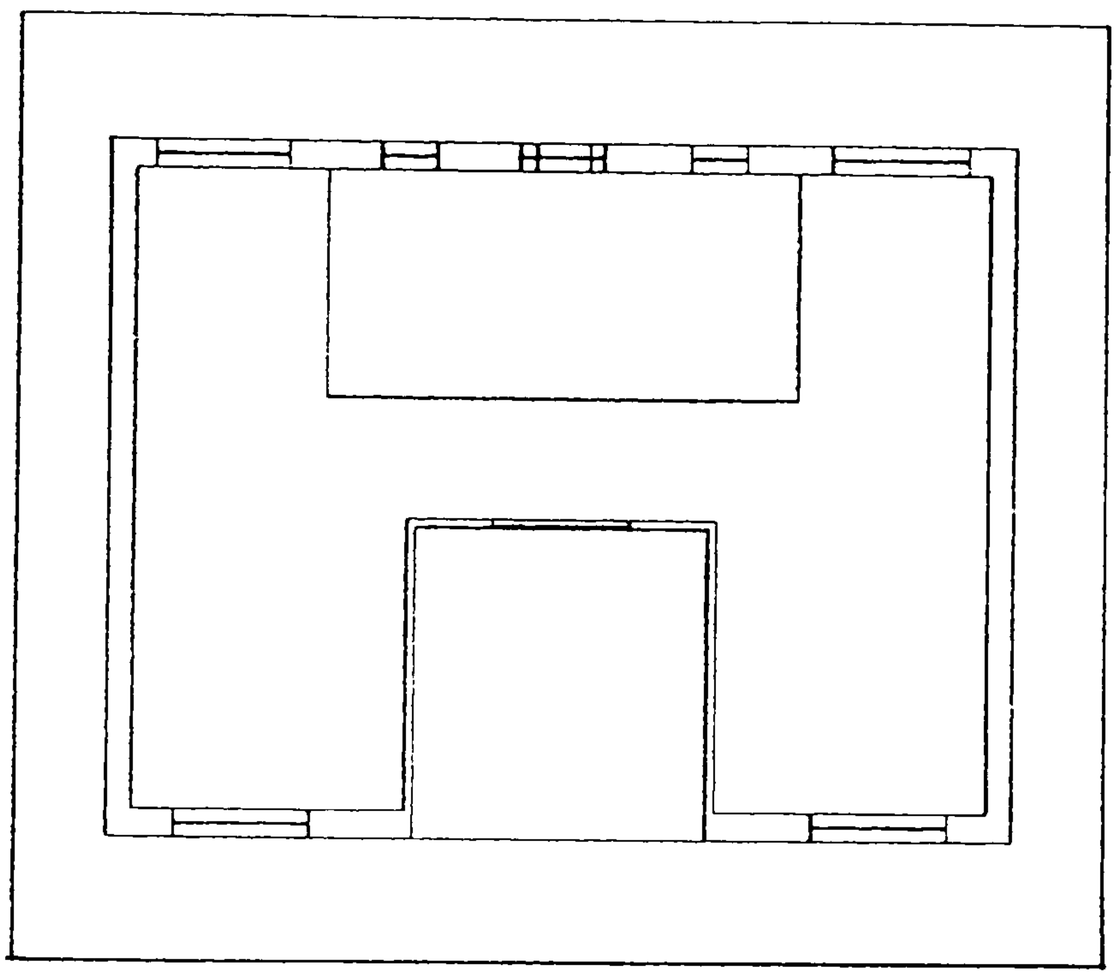
Exposed glazed space

The models are illustrated in Figures 4.01 - 4.03 on the following pages.

Entrance elevation



Ground floor plan



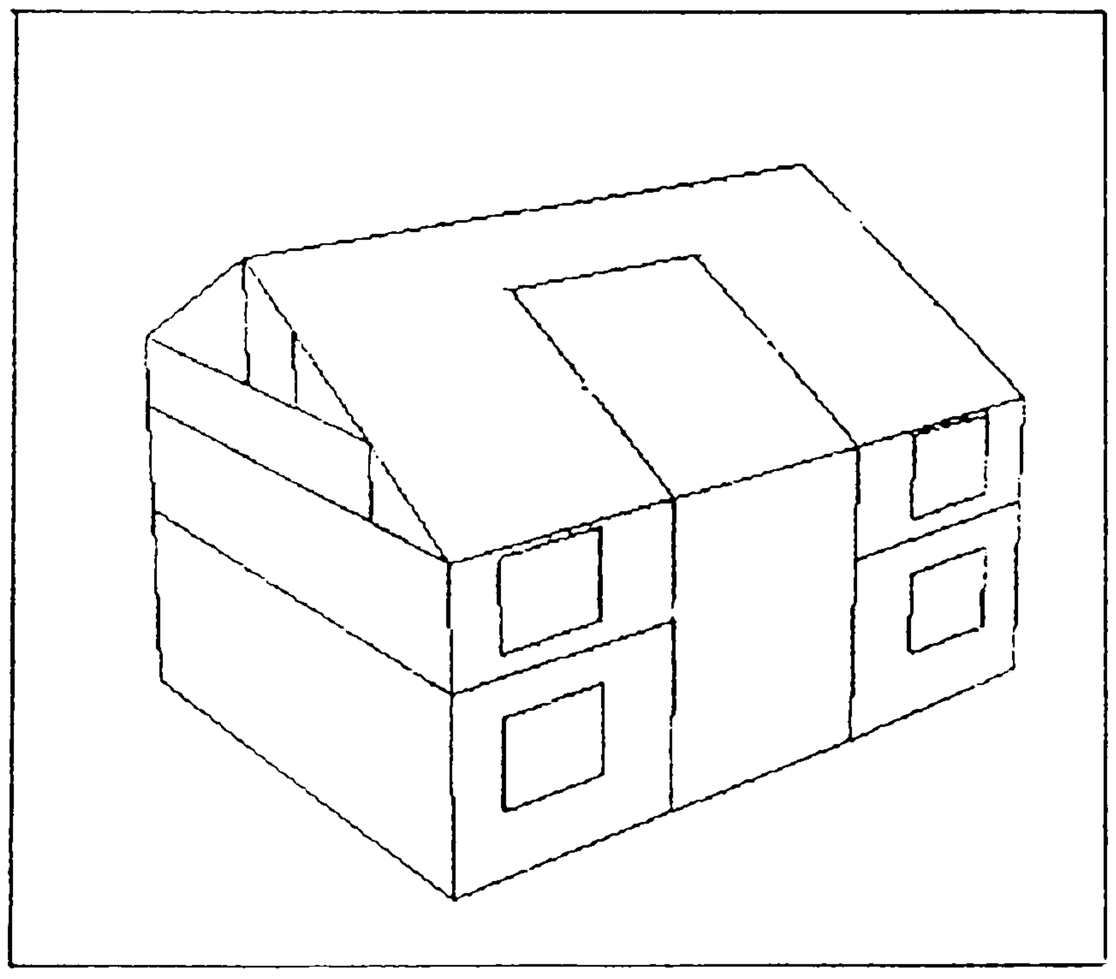
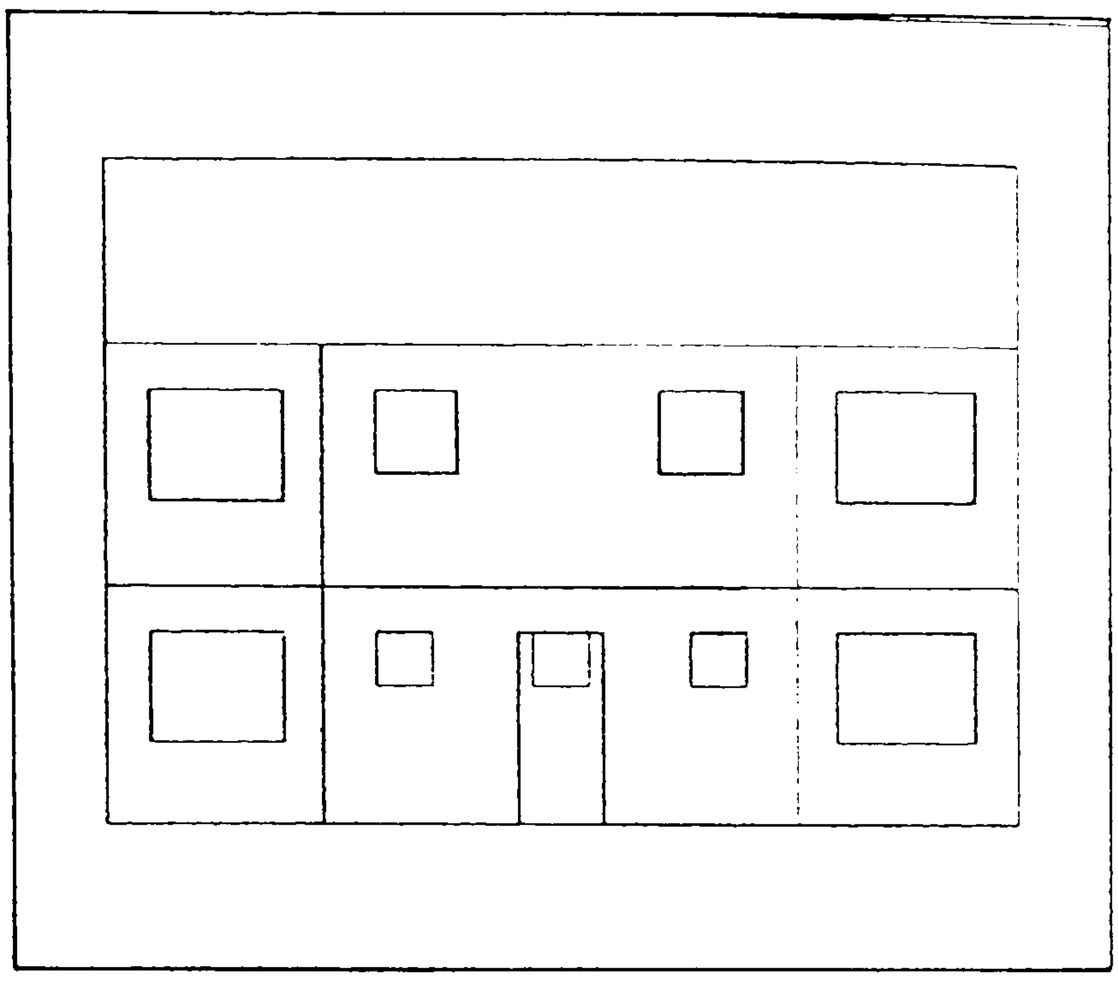
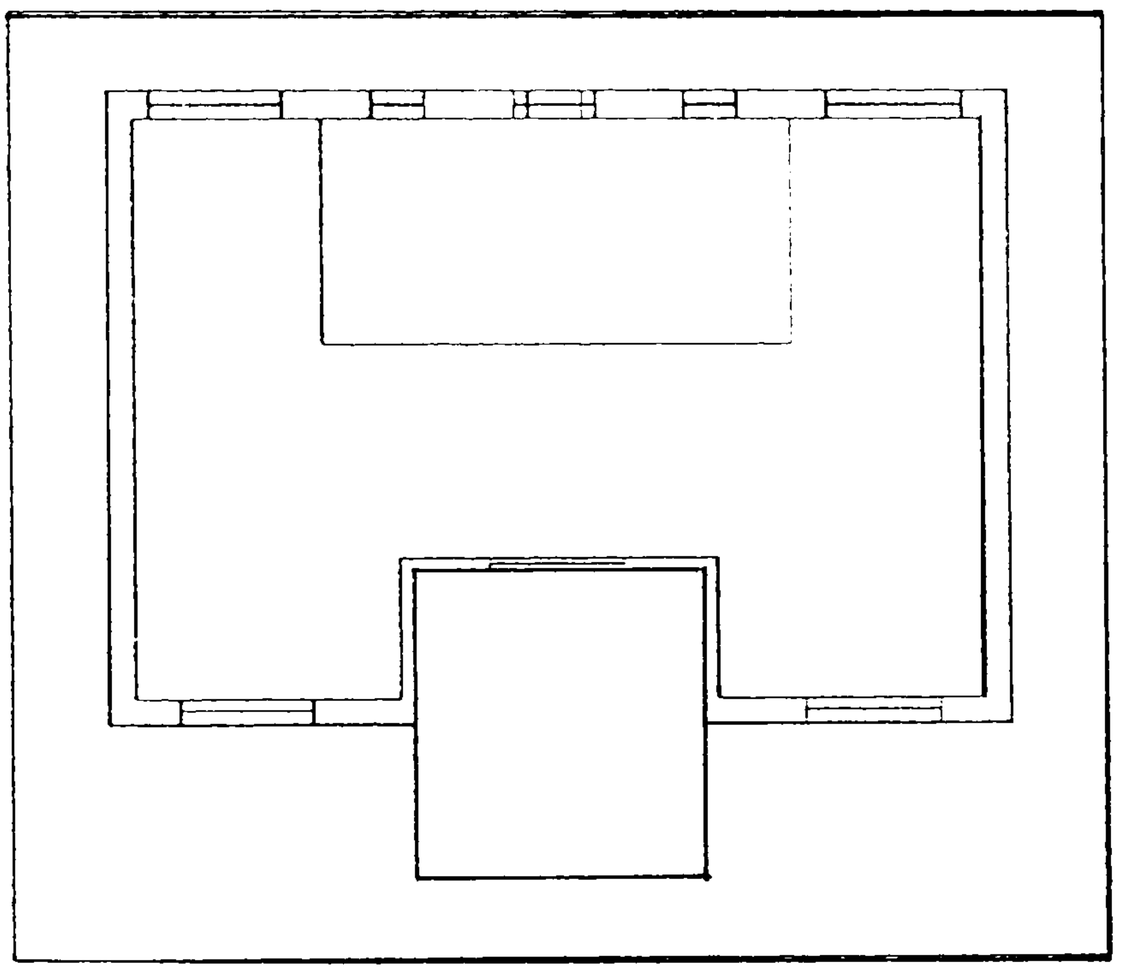


Figure 4.01 **The 110m^2 house with integral glazed space**

Entrance elevation



Ground floor plan



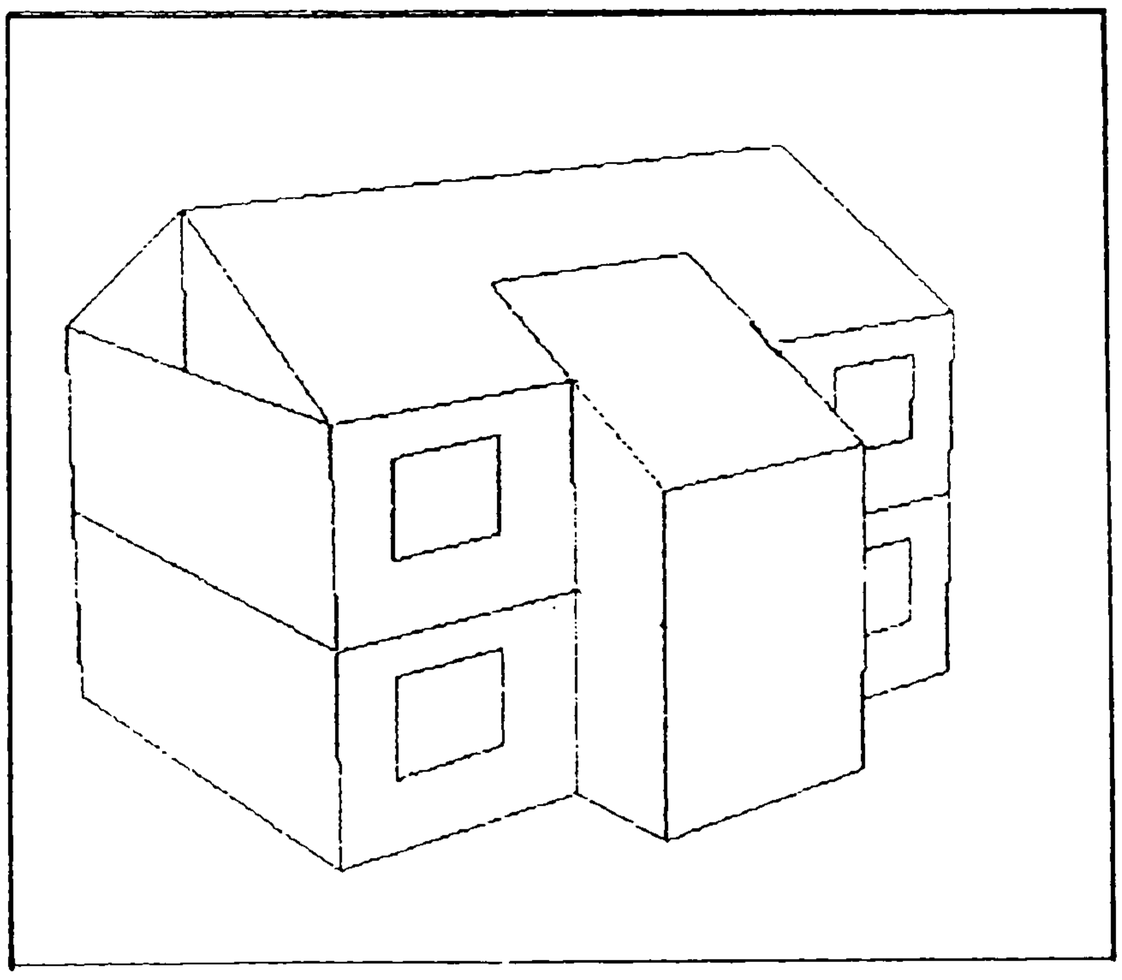


Figure 4.02 **The 110m^2 house with semi-exposed glazed space**

Entrance elevation

Ground floor plan

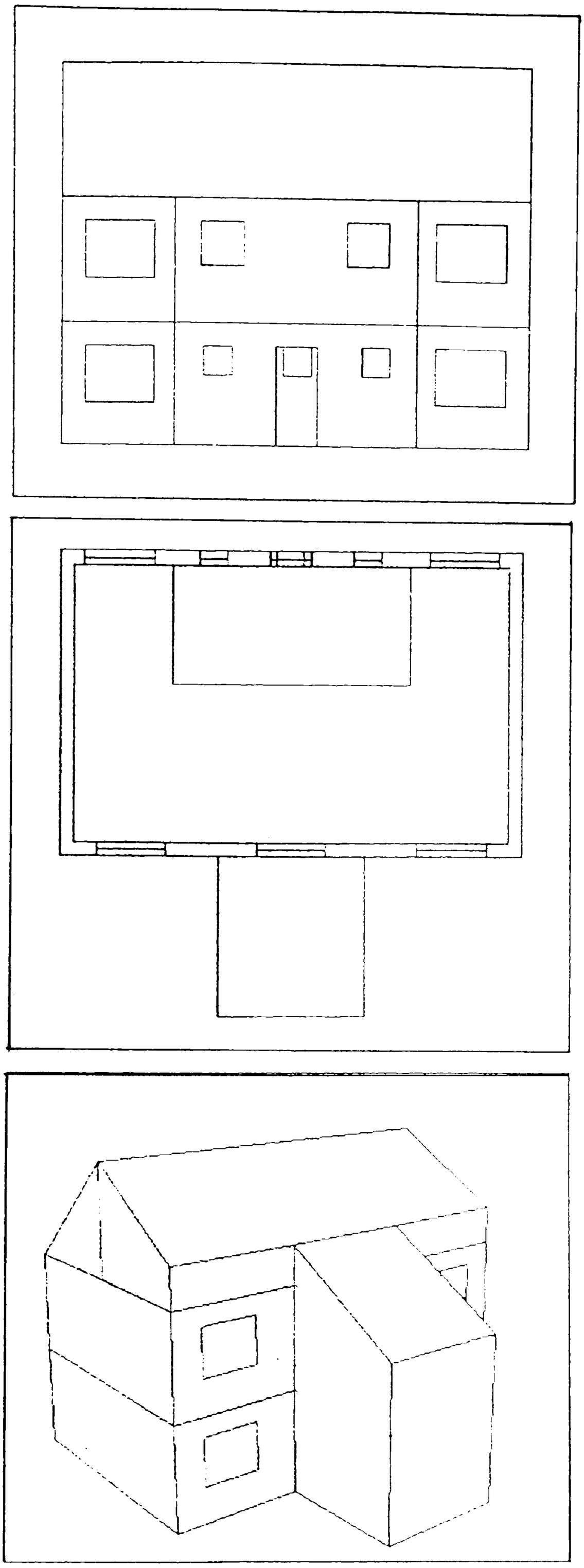


Figure 4.03 **The 110m^2 house with exposed glazed space**

The house windows were again arranged symmetrically on the front and rear facades of the models and similar areas and positions of windows were maintained in the three models. Again there was a close match in the area of windows and doors on the front and back of the house in order to keep exposure to solar radiation consistent for different orientations.
The models were divided into zones as shown in Table 4.01, care having been taken during the setting up of the models to maintain constant areas and volumes for each zone.

Table 4.01 **Zones in the 110m^2 model**

Zone 1 :Glazed space	11m^2	20% of ground floor area
Zone 2 :Living areas	42m^2	includes living room, dining room, kitchen
Zone 3: Ancillary areas	13m^2 ground floor 15m^2 first floor	areas of fleeting occupancy, includes circulation, bathrooms, utility room
Zone 4 :Bedroom areas	40m^2	includes bedrooms and airing cupboard
Zone 5 :House roofspace		

Internal conditions were applied to the zones as described in Chapter 2.07 Building Constructions were added as described in Chapter 2.08 using the first glazing option to the glazed spaces, [single glazing to the walls of the glazed space and double glazing to the roof].

Checking the models
The geometry of the models was checked, using the Surface Geometry and the Building Summary facilities of the Tas program in order to ensure that the areas and volumes of the zones were constant for all models.
Exploratory one day simulations were then performed in order to check that incidental gains such as those from human occupation and equipment were also constant for all the models.

Completion of the set of models
Each model was then copied to the four orientations and shadow calculations performed. Each orientation was then copied twice and the other glazing options added to the glazed spaces, all as described in Chapter 2.04 on simulation strategy.
At this stage the set of models consisted of;

- three types of glazed space, integral, semi-exposed and exposed
- all at four orientations
- all with three glazing types for the glazed space

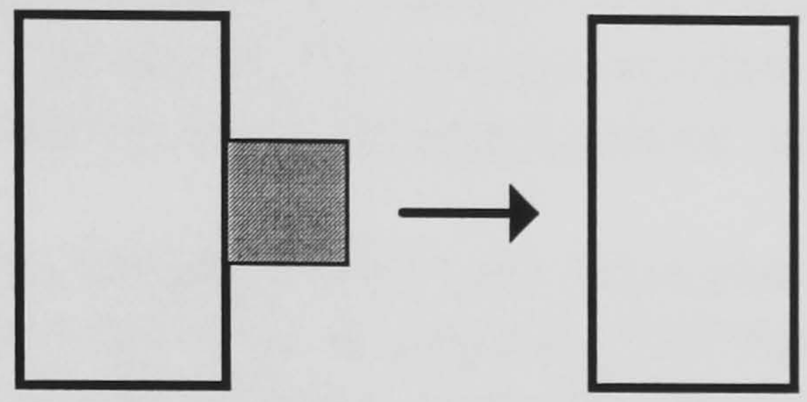
resulting in a total of 36 models.

Each model was simulated with an unheated and a heated glazed space.

Basic houses for comparison

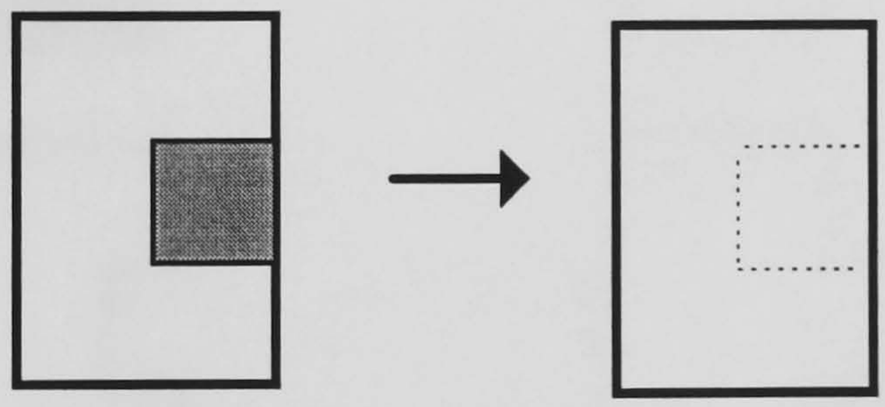
Basic house models without glazed spaces were also required for the comparison of the effect of the glazed space on heating loads and on overheating in adjoining rooms. The basic houses were adapted from the glazed space models in order that the area and volume of accommodation and the areas of external elements should be as close to those in the original models as possible.

110m^2 basic model



A basic house model of 110m^2 total internal floor area was produced by the removal of the glazed space from the exposed glazed space model. The glazed doors on the ground floor, the window on the first floor and the wall containing them, which had been enclosed within the glazed space, then became external elements. Their constructions had been entered as for the other external walls and double glazed window elements in the original model and so no change was needed in the new model. Internal conditions and heating strategies remained as for the exposed glazed space model.

132m^2 basic house model



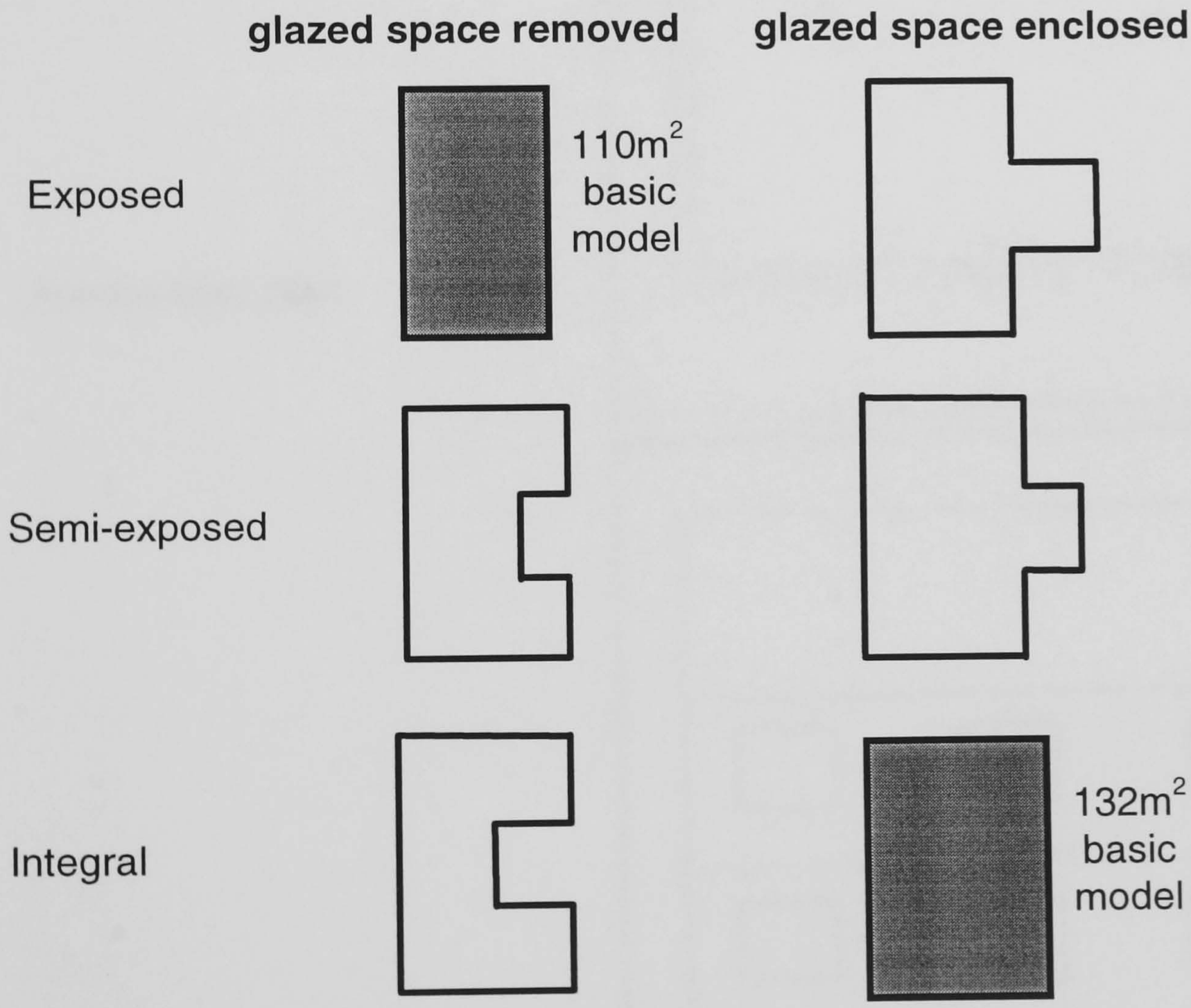
A second basic house model of 132m^2 total internal floor area was produced in order to provide a comparison for the heating load of the total volume of the house plus glazed space, enclosed by external wall construction. In order to achieve this the model with the integral glazed space was copied and amended so that the materials of external wall, sloping roof and floors of the glazed space were changed to those of the house. The internal window and glazed door were deleted and a window and a glazed door inserted in the external wall. An intermediate floor was introduced at first floor level in what had formerly been the glazed space area, giving a house of 132m^2 total floor area. [equal to the original house plus glazed space, on two floors].
For the 132m^2 basic house it was necessary to establish Internal Conditions for the original glazed space volume now enclosed within the building envelope and divided by the intermediate floor into a ground and a first floor room.

The Internal Conditions for the two rooms were as follows;

- The original heat gains from lighting [entered as W/m^2 of floor area] were divided equally between the two rooms.
- The heating pattern remained the same as for the heated glazed space.
- There were no occupancy or equipment gains, as for the glazed space.
- The infiltration rate into the two rooms was reduced to 0.75 ac/h in line with the enclosing construction.

In this way the former glazed space volume was experiencing the same internal conditions in both the basic and the glazed space models and so a comparison could be made between the effects of a glazed or solid envelope to the central portion of the house. For the rest of the accommodation internal conditions and heating strategies remained as for the integral glazed space model.

It could be argued that six models would result from the concept of the creation of the basic house by the removal or enclosure of all the glazed space arrangements. However, it was felt that in four cases this would result in impractical forms of house plans and the generation of large quantities of inconsequential data. For this reason only the two basic house plans described previously were adopted, as shown below,



The $110m^2$ and $132m^2$ basic house models were copied to four orientations and shadow calculations were performed.
The basic house models are illustrated overleaf in Figures 4.04 and 4.05.

Entrance elevation

Ground floor plan

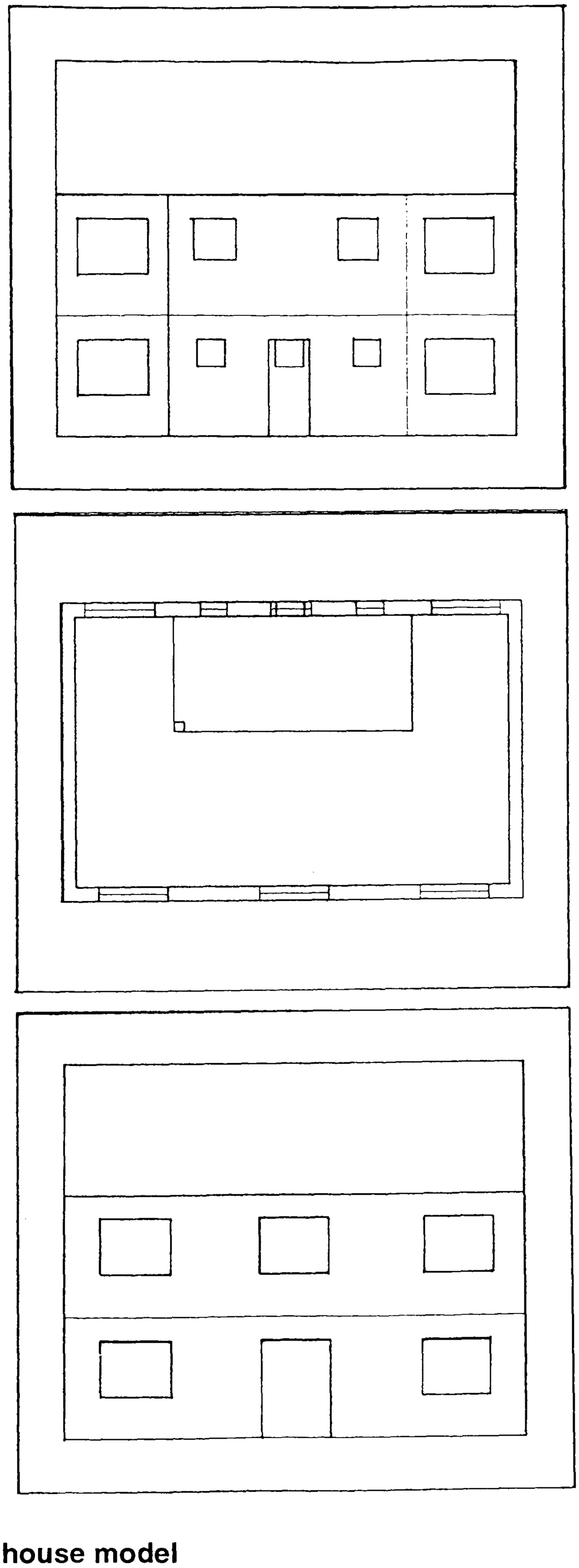
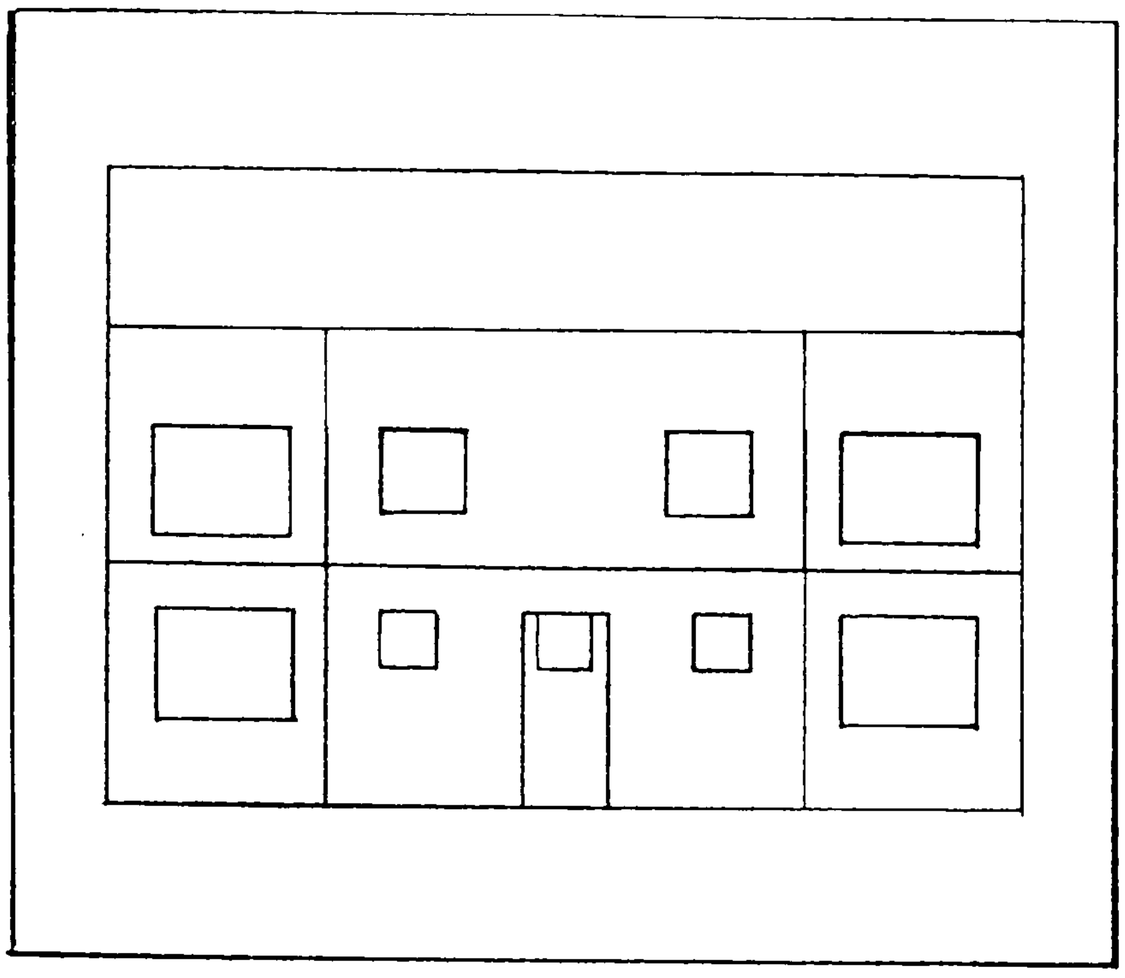
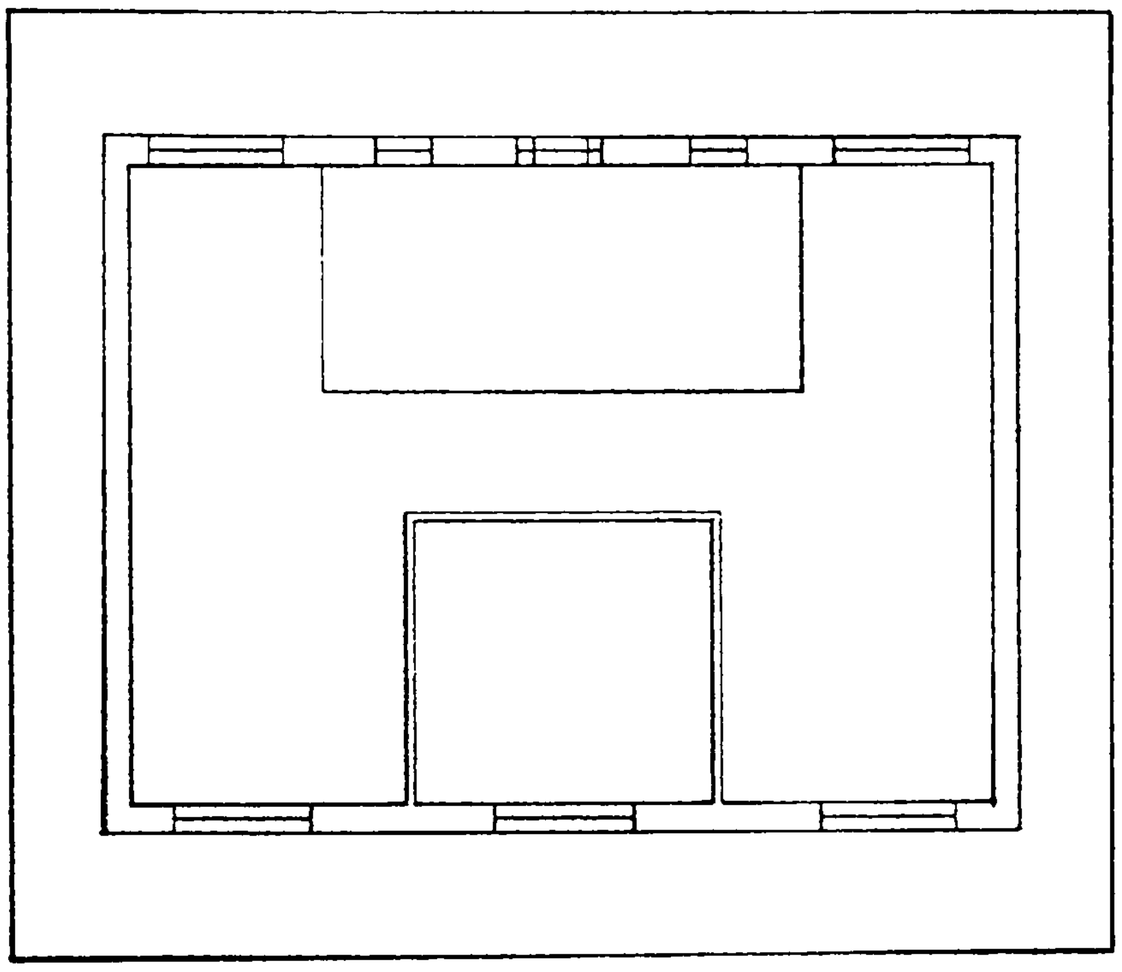


Figure 4.04 **The 110m^2 basic house model**



Entrance elevation



Ground floor plan

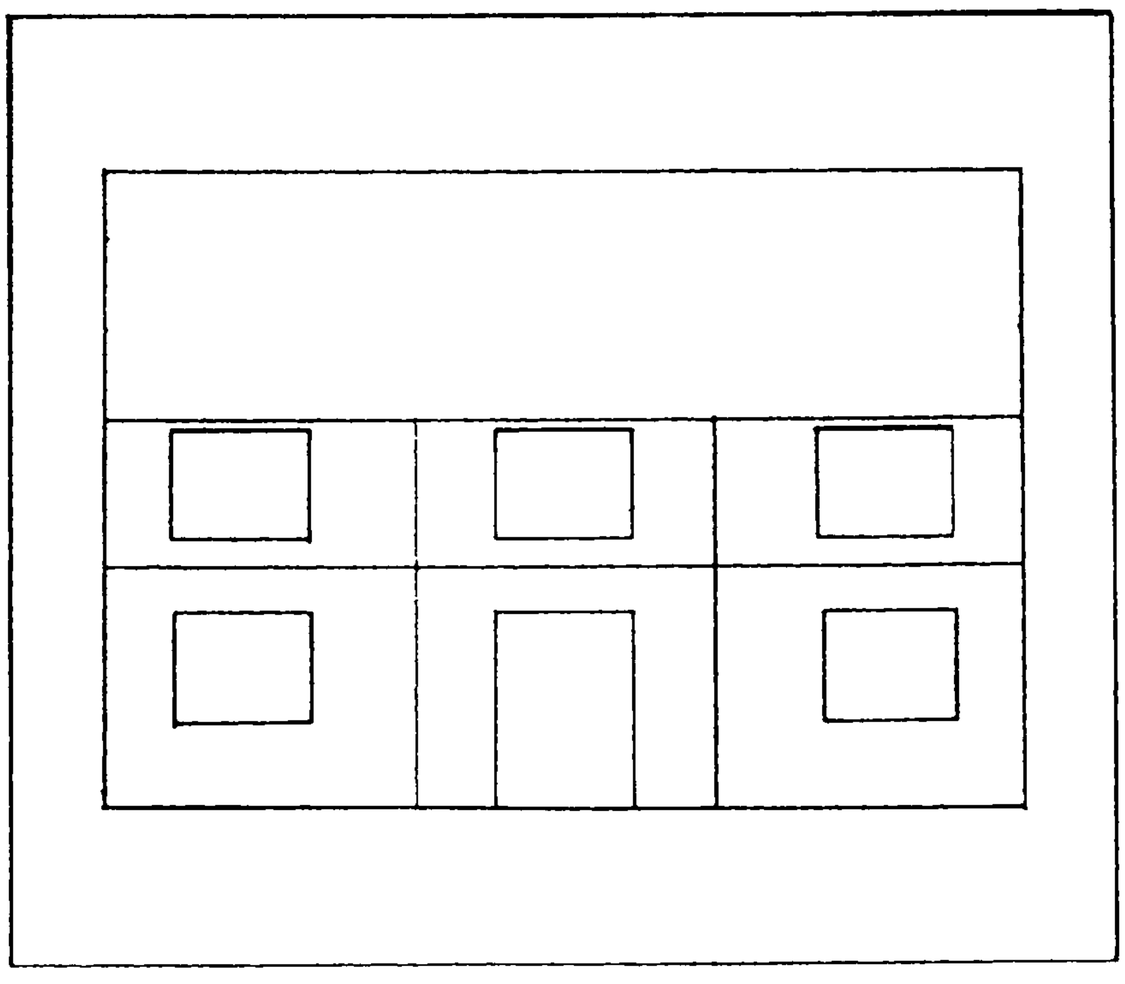


Figure 4.05 **The 132m^2 basic house model**

4.02 Initial Simulations

Initial thermal simulations were then undertaken, for the 36 models with unheated and heated glazed spaces and the 8 models of the basic house, using the weatherfile for the south-east of Britain. The approach to air infiltration and air movement in these initial simulations is the same as that for the first set of models and is outlined again below.

Air infiltration and air movement

For the initial simulations, outside air entered the interior spaces only by infiltration through the building fabric, at rates set out in the internal conditions data -sheets, Chapter 2.07. No attempt was made at this stage to simulate ventilation by opening windows and doors. The results of these simulations provided a standard for comparison with the results of further studies, described later, in which strategies to enhance the performance of the glazed space in terms of a comfortable low energy environment were incorporated. Air movement between the zones was not included in the simulations.

Simulation results

Simulation results were obtained for **the three models with an unheated glazed space**, for four orientations and three glazing types for;

- the number of hours of comfortable temperatures in the glazed space, on a monthly basis
- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in the living rooms and bedrooms

Simulation results were obtained for **the models with a heated glazed space,** for four orientations and three glazing types for;

- the monthly space heating load for the house
- the monthly space heating load for the glazed space

Simulation results were obtained for **the two models without a glazed space** for;

- the monthly space heating load for the house
- the number of hours of uncomfortably hot air temperatures in the living rooms and bedrooms

4.03 The Results of the Initial Simulations

The results of the initial simulations and discussion of the implications are presented as follows;

- Comparison of the number of comfortable hours in the unheated glazed spaces on a **monthly** basis, organised by the type of glazed space and by orientation, Figures 4.06-4.08, north facing; Figures 4.09-4.11, south facing; Figures 4.12-4.17, east and west facing.

- Comparison of the annual space heating loads of the basic houses and the house with a heated or unheated glazed space, organised by orientation, Figures 4.18 - 4.21.

- The effect of the presence of the glazed space on overheating in the adjoining living rooms and bedrooms, Figures 4.22 - 4.23.

It must be noted that the glazed spaces are are not ventilated but that the simulation results represented in Figures 4.06 - 4.17 form a datum for comparison with the results of further studies which investigate the effect of ventilation on the number of comfortable hours predicted.

Identification of the models

In the presentation of the results the models are identified by the type of glazed space, orientation and glazing materials of the glazed space, for example;

integral/north/single, semi-exposed/east/double, exposed/west/low E

where the glazing materials are as follows;

single : single glazed walls and double glazed roof

double : double glazed walls and roof

low E : double glazed, low emissivity, walls and roof

The charts are organised by orientation, as for the single storey models, and compare the effects of the choice of glazing on the number of hours of comfortable temperatures per month which can be achieved during the daytime, [morning and afternoon results added together] and evening periods. The charts also indicates the hours which are too cold and those which are too hot, as shown in the key on each page.
The morning and afternoon results are combined, as periods of use of a glazed space during the daytime are difficult to predict. Division of the daytime period would also lead to complications in reading the charts. A breakdown of the daytime period is included in Appendix H.

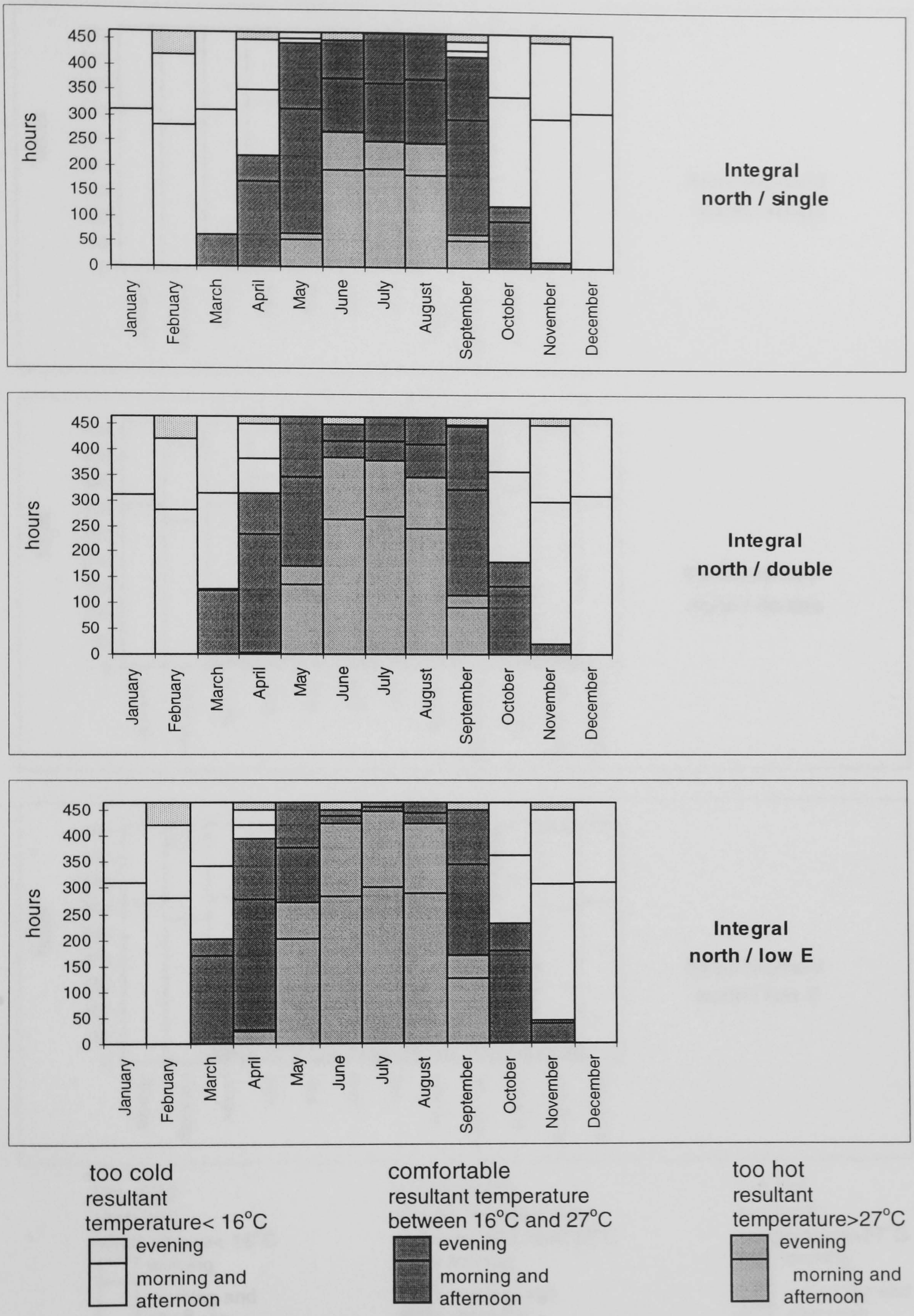


Figure 4.06 **Resultant temperatures in the north facing, integral glazed spaces**

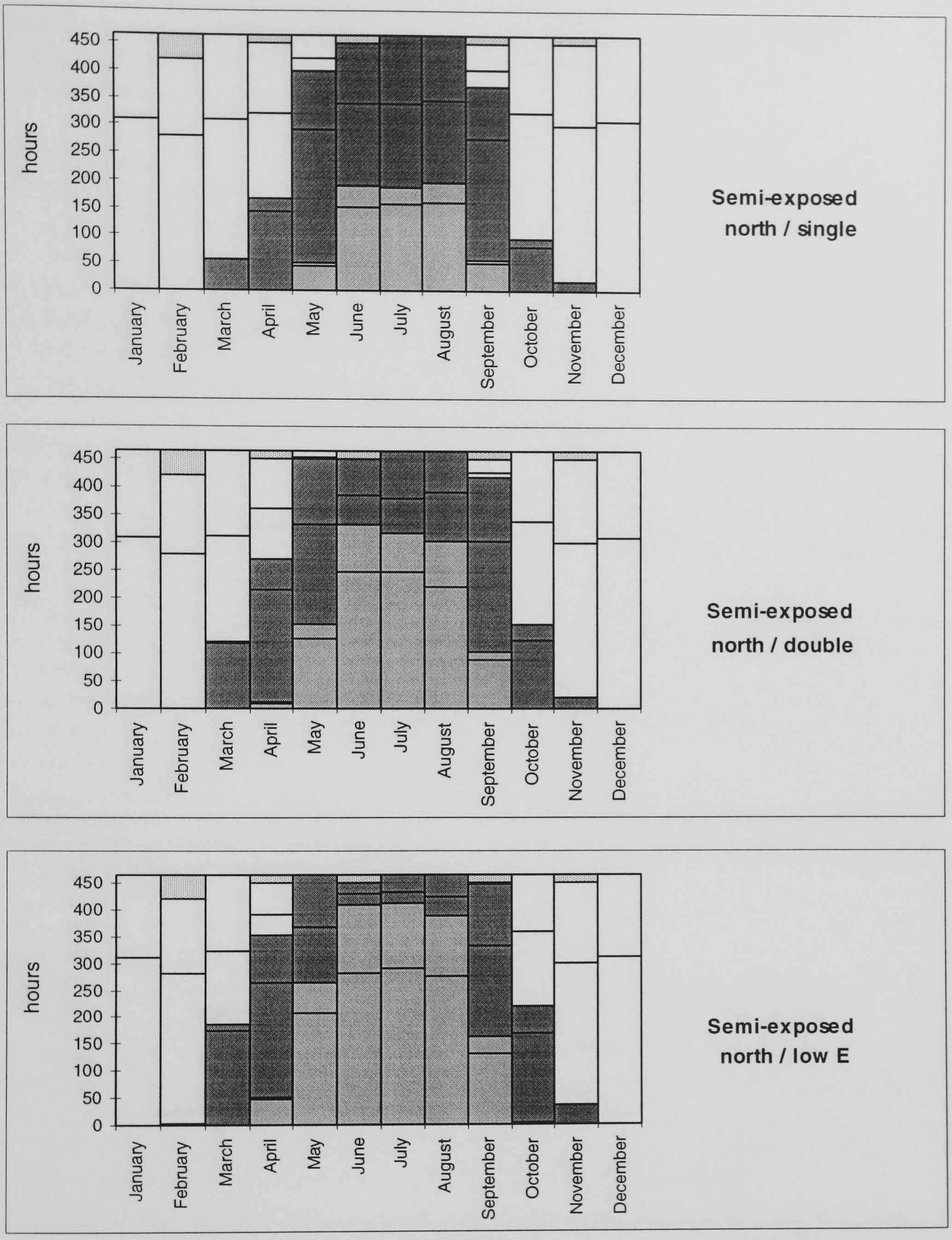


Figure 4.07 **Resultant temperatures in the north facing, semi-exposed glazed spaces**

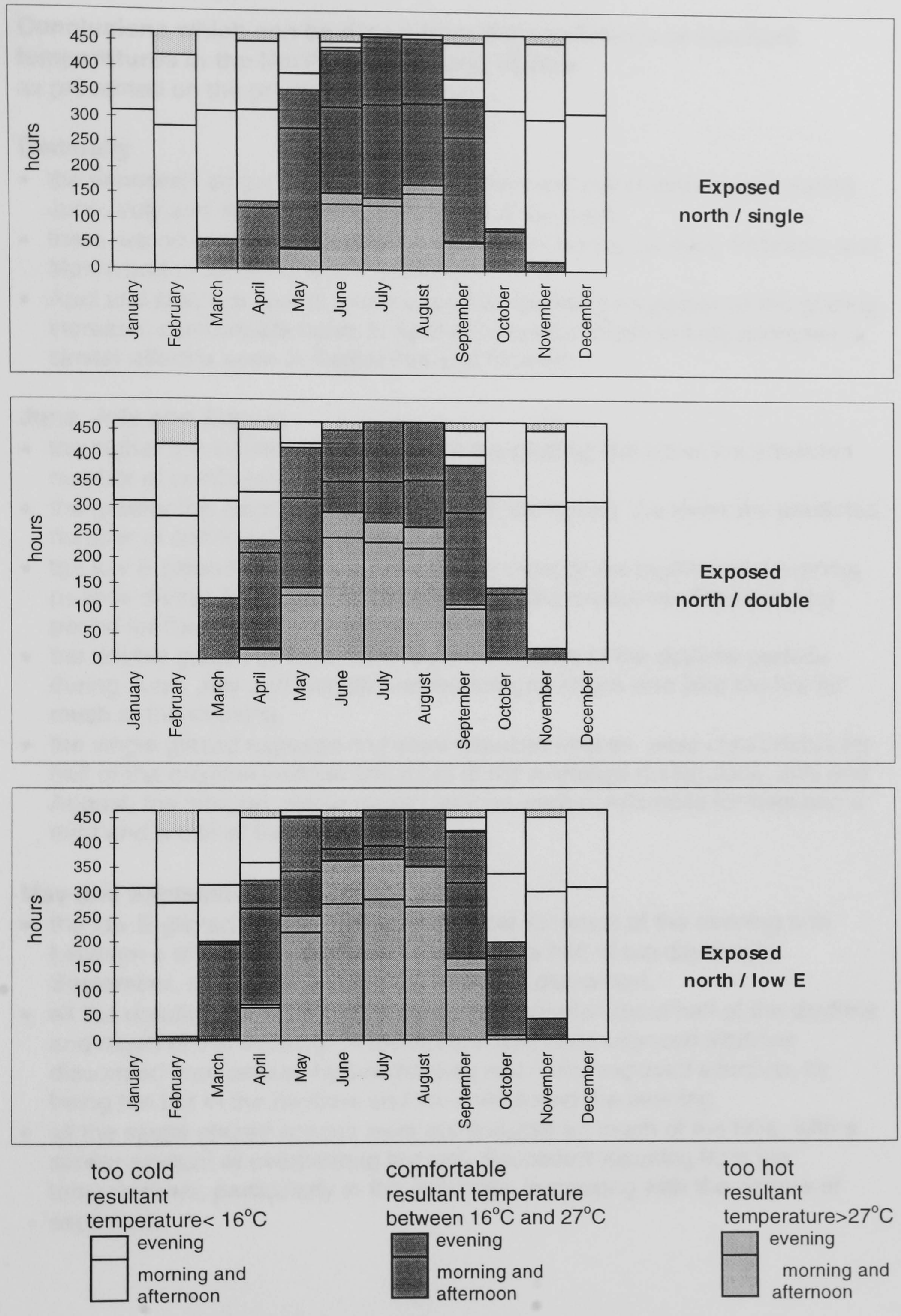


Figure 4.08 **Resultant temperatures in the north facing, exposed glazed spaces**

Conclusions which can be drawn from the predictions of resultant temperatures in the North facing glazed spaces
as presented on the previous three pages

Generally

- the exposed / single situation provides the most comfortable hours during June, July and August, the integral / low E the least.
- there are no comfortable hours for any model during January, February and March and virtually none in November
- April and May are pivotal months; as the insulating properties of the glazing increase, comfortable hours in April increase but those in May decrease, a similar effect is seen in September and October.

June, July and August :

- the higher the insulating properties of the glazing, the lower the predicted number of comfortable hours.
- the greater the degree of integration with the house, the lower the predicted number of comfortable hours.
- the low E glazed spaces were too hot for most of the daytime and evening periods during June, July and August, with the exception of the evening period for the exposed, low E space.
- the double glazed spaces were too hot for much of the daytime periods during June, July and August and the integral space was also too hot for much of the evening.
- the single glazed exposed and semi-exposed spaces, were comfortable for half of the daytime periods and most of the evenings during June, July and August, the integral, single glazed spaces were comfortable for between a third and a half of these periods.

May and September

- the low E glazed spaces were comfortable for much of the evening and between a third of the daytime, in May and a half of the daytime in September, overheating being the cause of discomfort.
- all the double glazed spaces were comfortable for about half of the daytime and much of the evening. In the integral and semi-exposed situtions discomfort was caused by overheating and in the exposed situation, by being too hot in the daytime and too cold during the evening.
- all the single glazed spaces were comfortable for much of the time, with a similar amount of overheating but with discomfort resulting from low temperatures, particularly in the evenings, increasing with the degree of exposure.

March, April and October:

- between a quarter and a half of the hours were comfortable during the daytime period for all glazing types and situations,
- during March and October discomfort was caused by low temperatures.
- during April discomfort was caused mainly by low temperatures but to a lesser extent high temperatures were also the cause in the low E spaces, in particular the exposed situation.

November :

- a very small proportion of comfortable hours,during the daytime period,much the same for all situations but slightly more for the low E glazed types.
- discomfort caused by low temperatures.

January, February and December :

- no comfortable hours for any situation or glazing type.

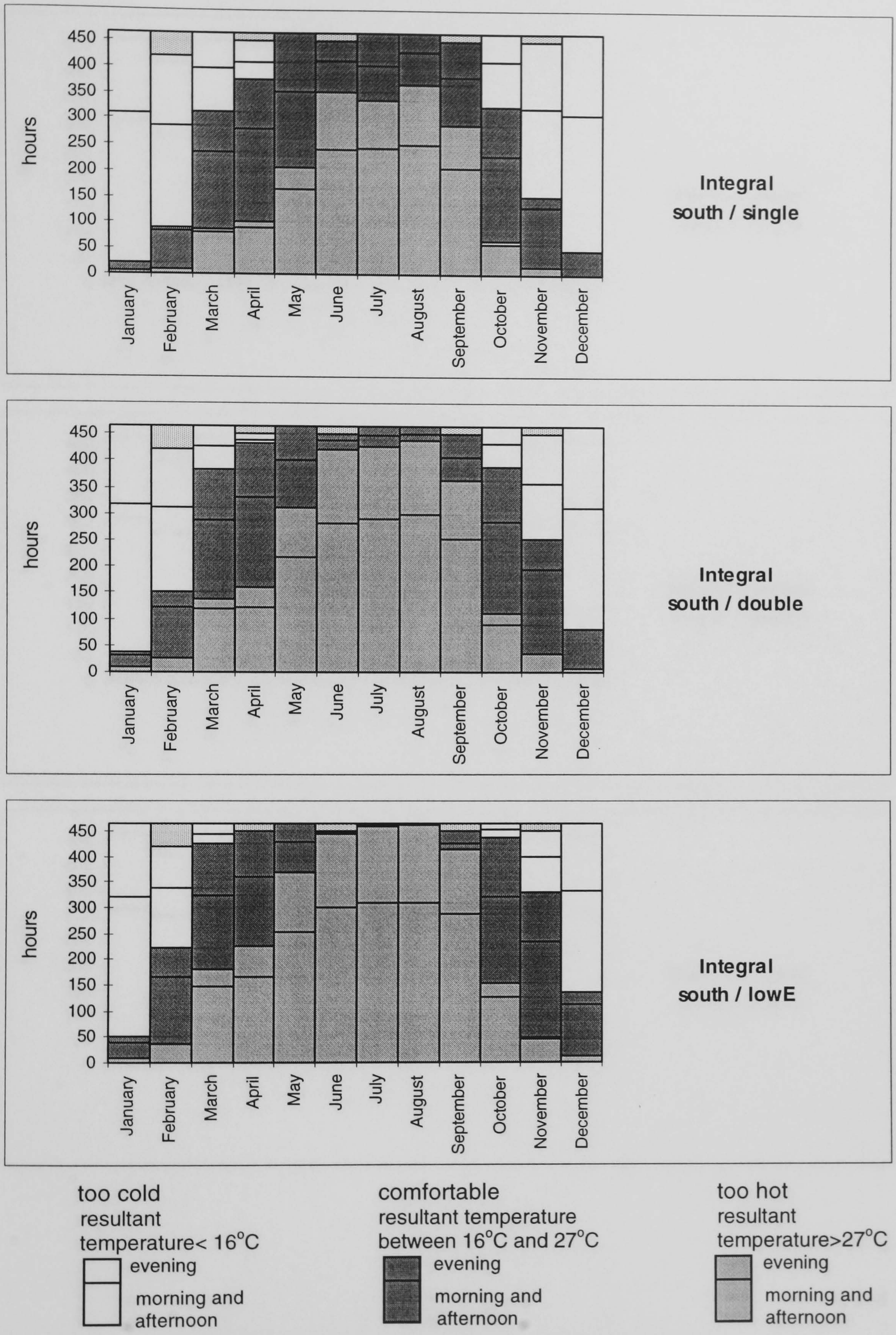


Figure 4.09 **Resultant temperatures in the south facing, integral glazed spaces**

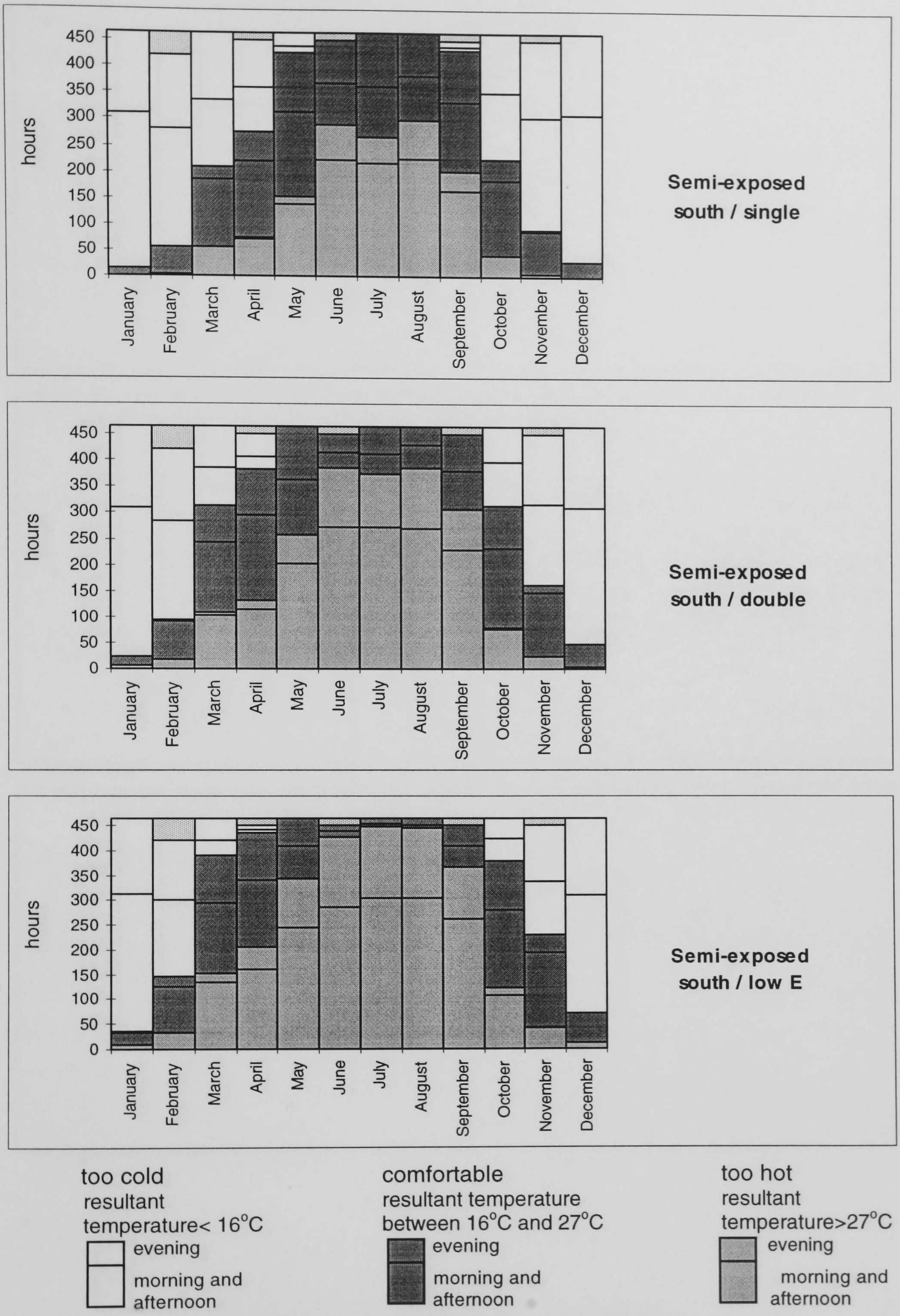


Figure 4.10 **Resultant temperatures in the south facing, semi-exposed glazed spaces**

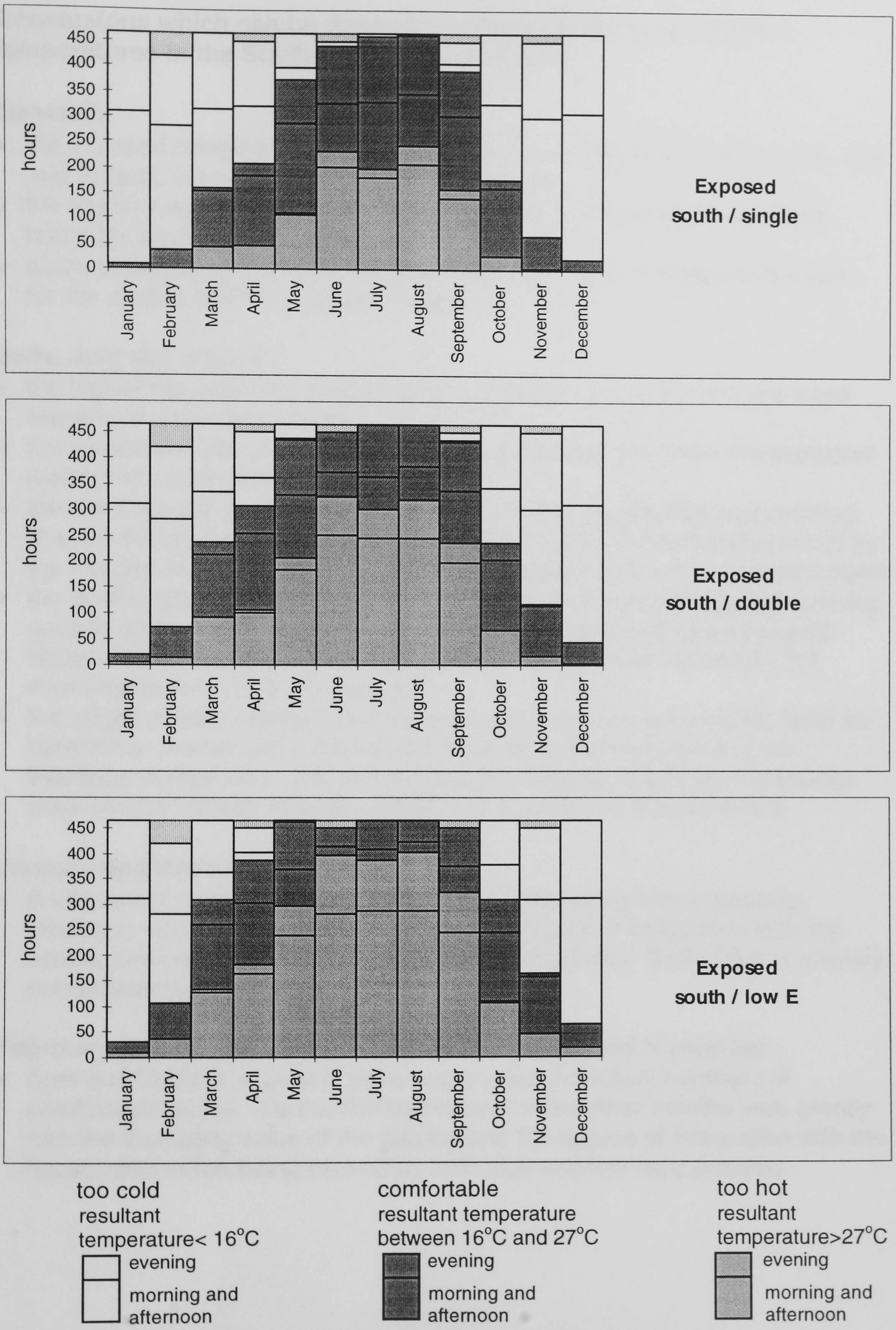


Figure 4.11 **Resultant temperatures in the south facing, exposed glazed spaces**

Conclusions which can be drawn from the predictions of resultant temperatures in the South facing glazed spaces

Generally

- the exposed /single model had the most comfortable hours during June, July and August, the integral / low E model the least.
- the daytime hours of comfort were rarely more than half of the available hours for any month or model.
- hours when the resultant temperature is too hot occur throughout the year for the double and low E glazed models.

June, July and August :

- the higher the insulating properties of the glazing, the lower the predicted number of comfortable hours.
- the greater the degree of integration with the house, the lower the predicted number of comfortable hours.
- the low E glazed spaces were too hot for most of the daytime and evening periods during June, July and August, with virtually no comfortable hours for the integral situation and very few for the exposed and semi-exposed models
- the double glazed spaces were too hot for much of the daytime and evening periods during June, July and August for the integral and semi-exposed situations, the exposed space was also too hot for much of the day but comfortable for half of the evenings.
- the single glazed, exposed and semi-exposed spaces, were comfortable for between a quarter and a third of the daytime periods and most of the evenings during June, July and August, the integral, single glazed spaces were comfortable for between a third and a quarter of these periods.

January and December :

- A very small number of comfortable hours, increasing with increasing insulation value of the glazing and with the degree of integration with the house, particularly for the integral model in December. Discomfort is caused predominantly by low temperatures.

February, March, April, May, September, October and November :

- April and October appear to have reasonably consistent numbers of comfortable hours. The comfortable hours for the other months vary greatly with the insulating value of the glazing and the degree of integration with the house, discomfort being caused by both high and low temperatures.

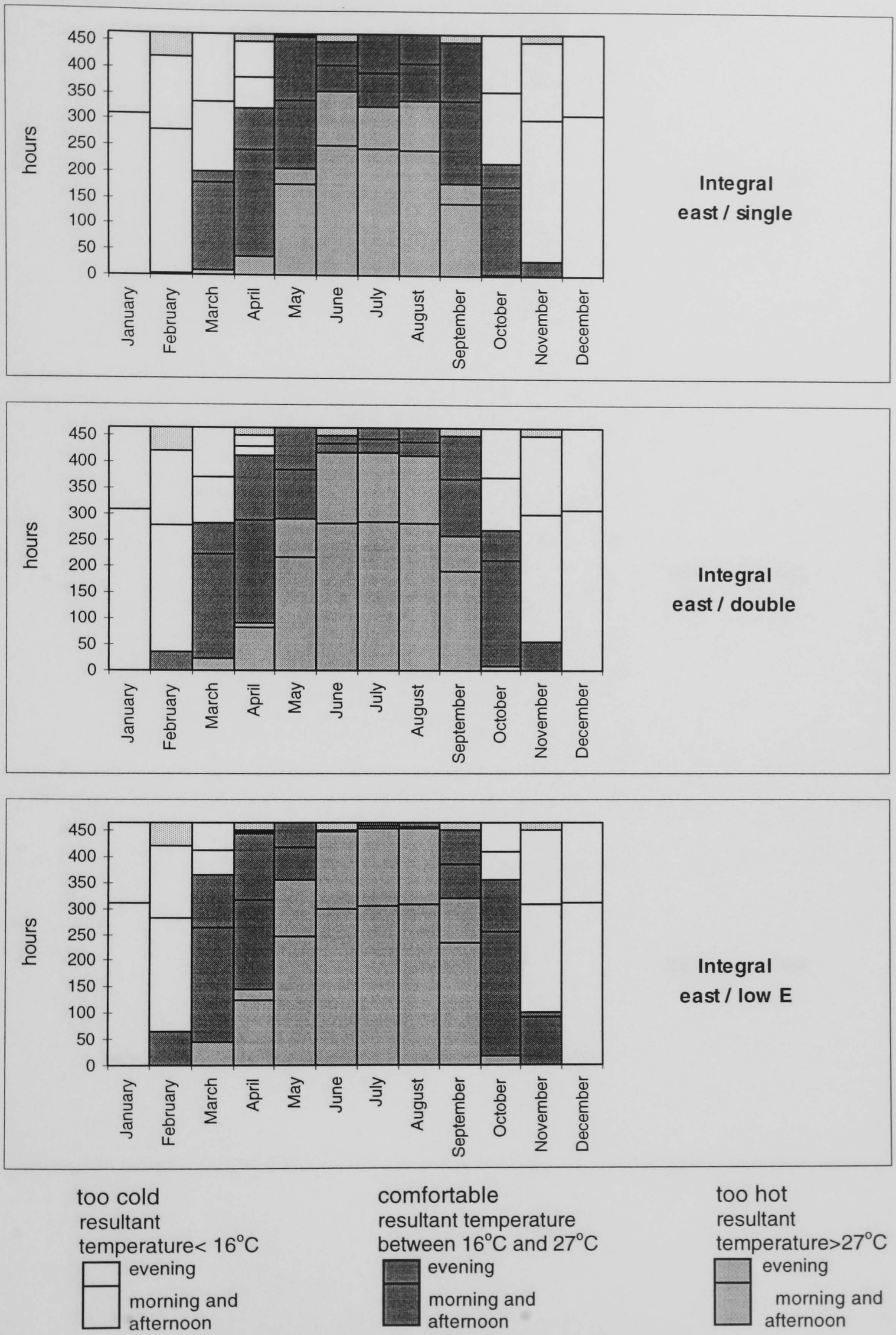


Figure 4.12 **Resultant temperatures in the east facing, integral glazed spaces**

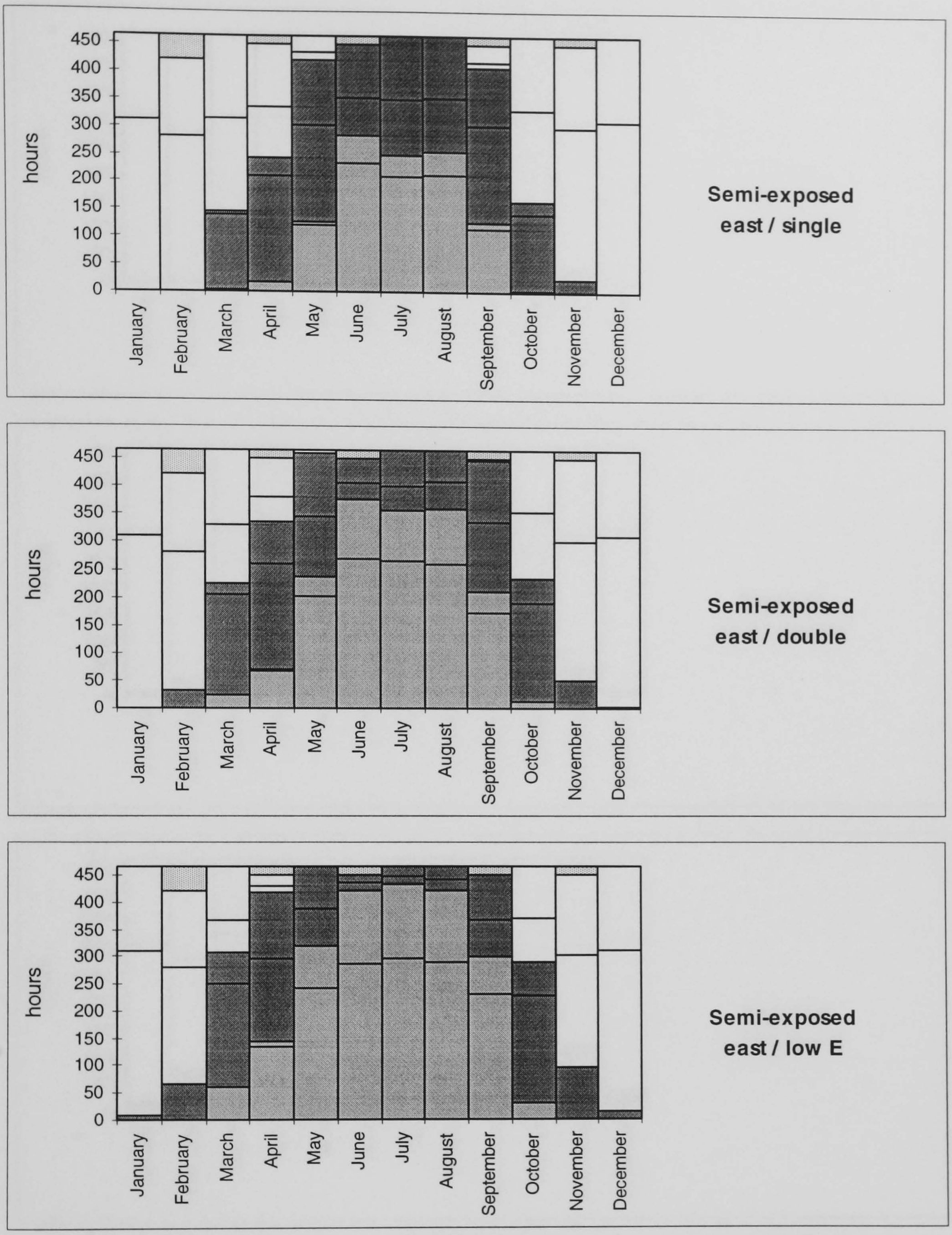


Figure 4.13 **Resultant temperatures in the east facing, semi-exposed glazed spaces**

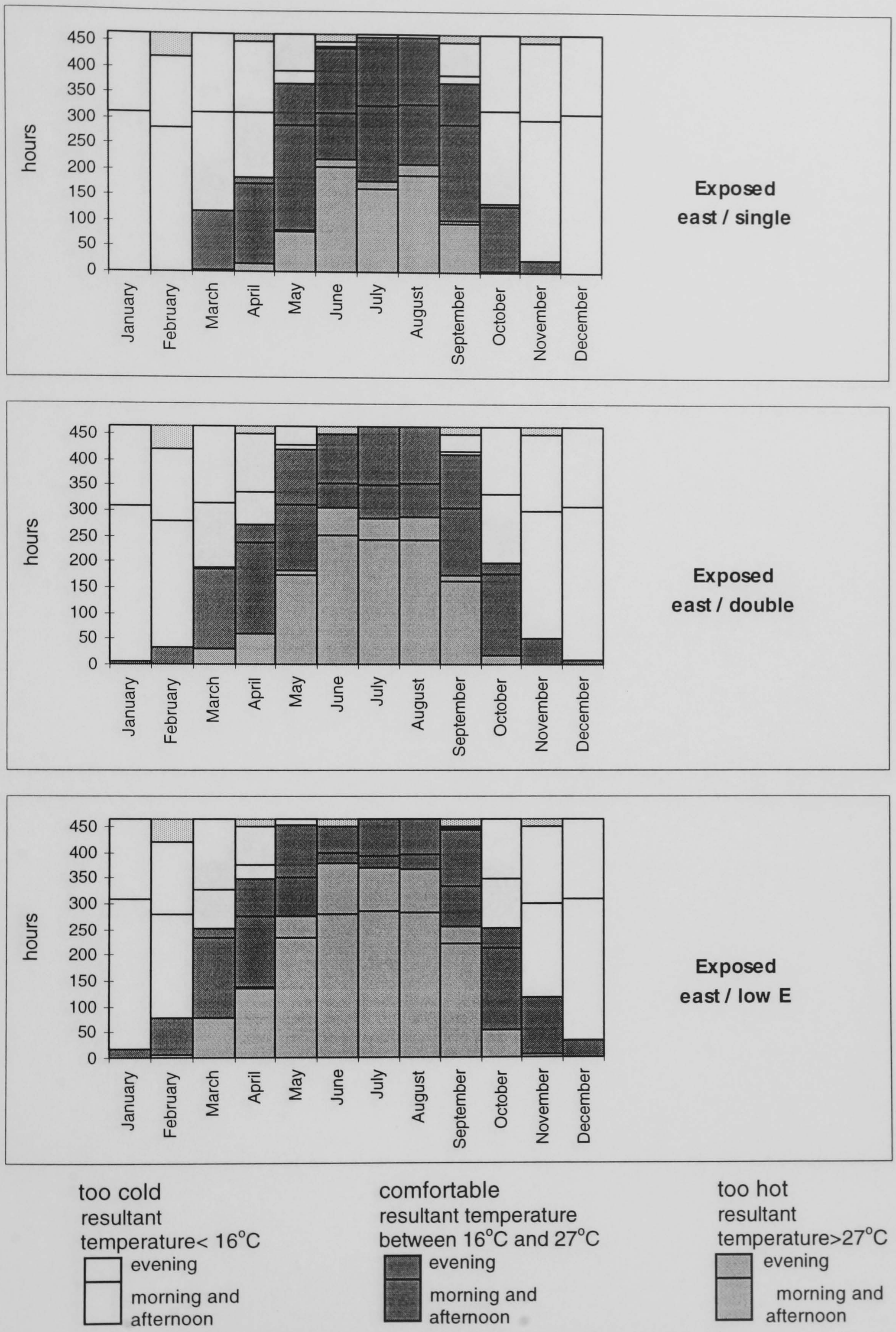


Figure 4.14 **Resultant temperatures in the east facing, exposed glazed spaces**

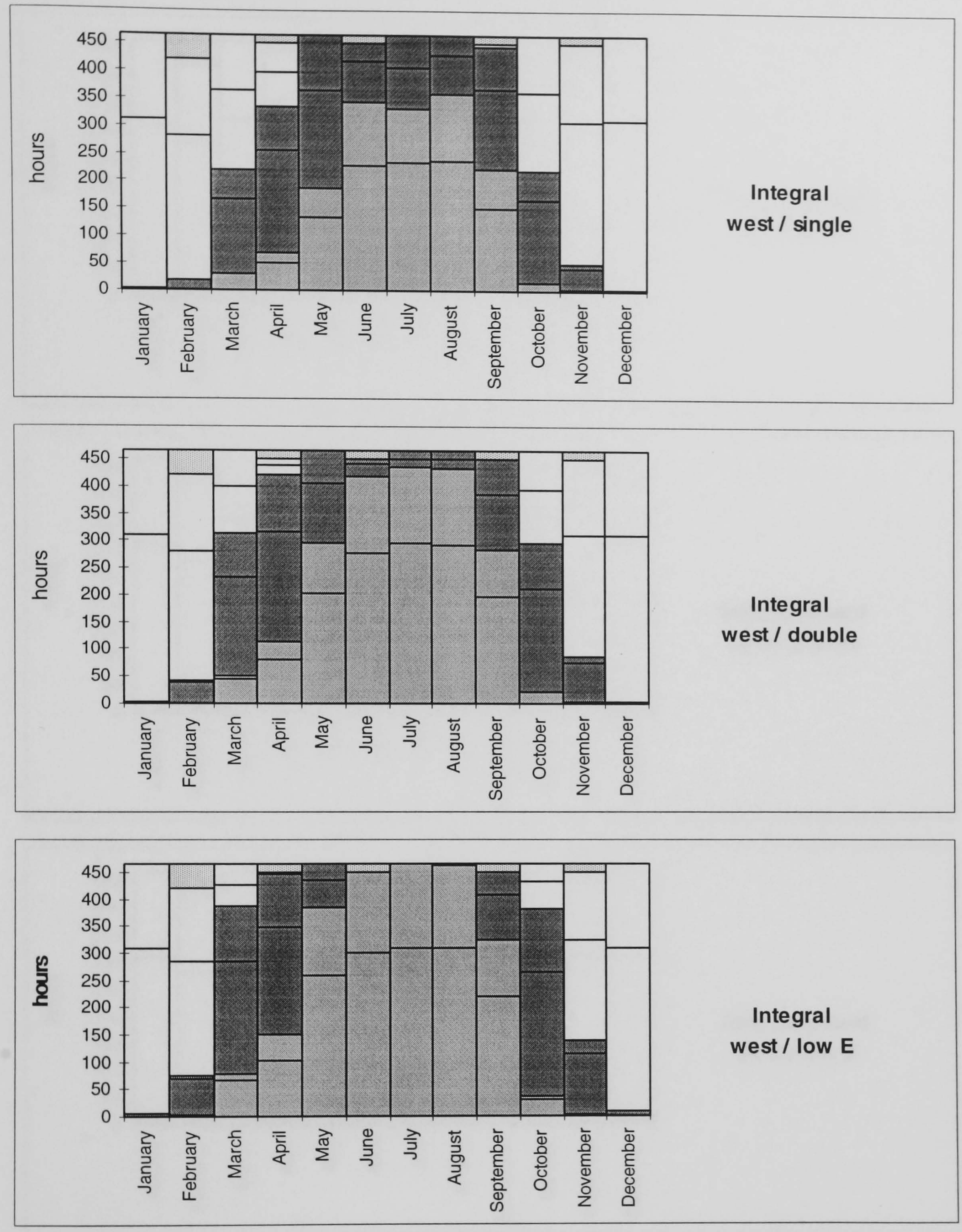


Figure 4.15 **Resultant temperatures in the west facing, integral glazed spaces**

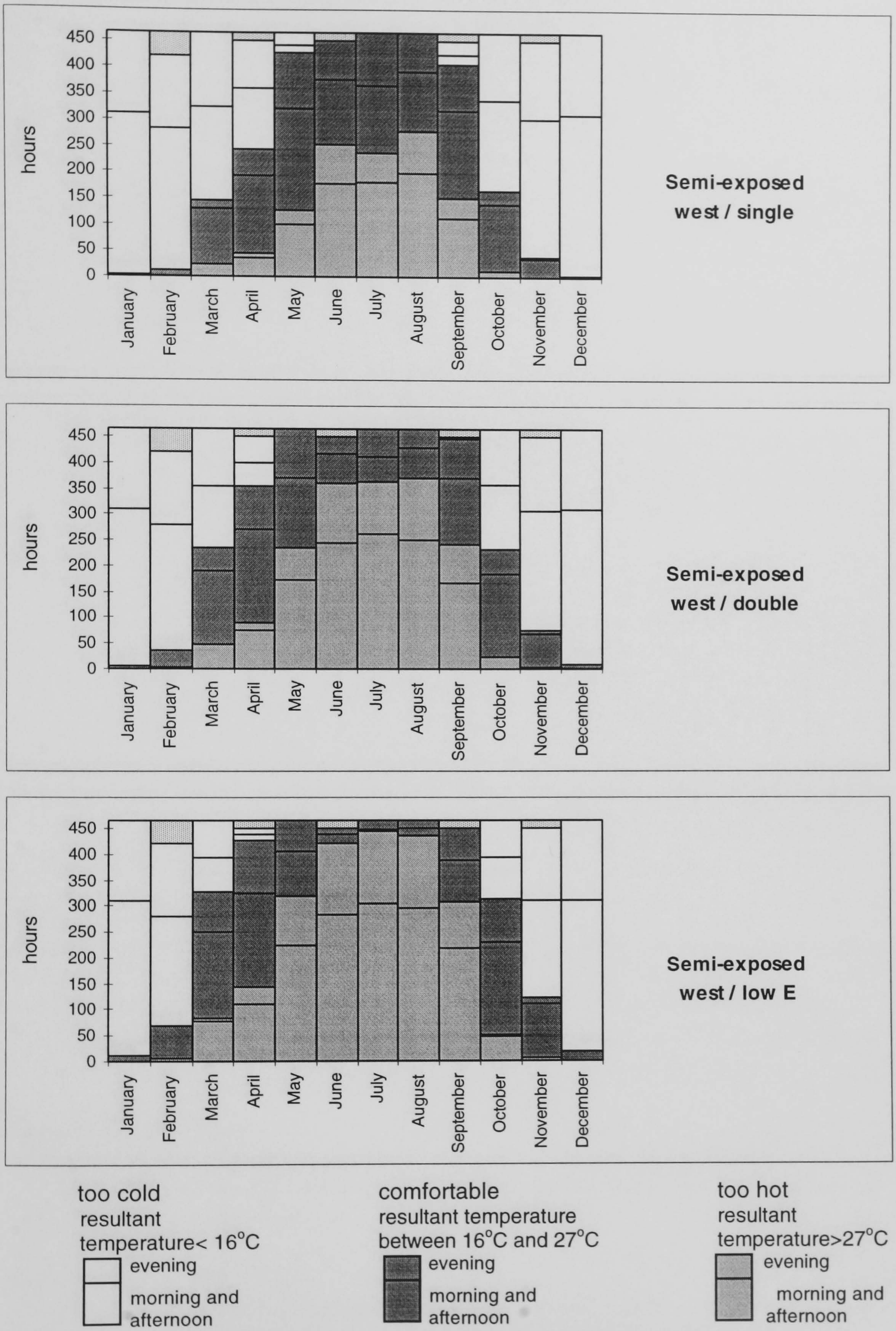


Figure 4.16 **Resultant temperatures in the west facing, semi-exposed glazed spaces**

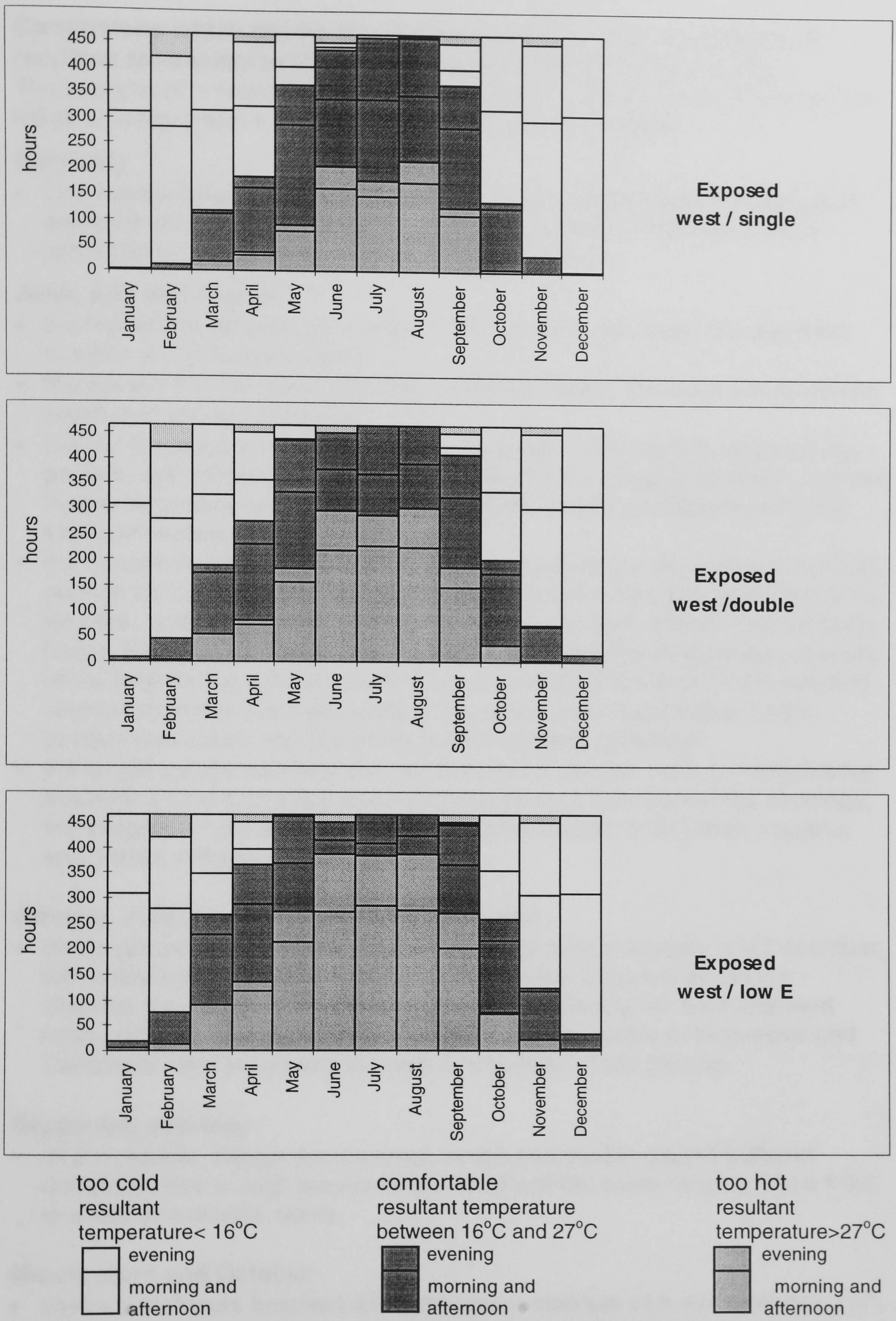


Figure 4.17 **Resultant temperatures in the west facing exposed glazed spaces**

Conclusions which can be drawn from analysis of the predictions of resultant temperatures in the East and West facing glazed spaces
The patterns of comfortable hour distribution for the east and west orientations follow a similar pattern and so have been analysed together.

Generally

- The results indicate that with increasing exposure the western orientations are more comfortable in the daytime and the eastern orientations more comfortable in the evenings, from May to September

June, July and August :

- the higher the insulating properties of the glazing, the lower the predicted number of comfortable hours.
- the greater the degree of integration with the house, the lower the predicted number of comfortable hours
- the low E glazed spaces were too hot for most of the daytime and evening periods, with virtually no comfortable hours for the integral situation, very few for the semi-exposed and less than a quarter of the available hours in the exposed models
- the double glazed spaces were too hot for much of the daytime and evening periods for the integral model. The semi-exposed model was comfortable for less than a quarter of the daytime hours and less than a third of the evening hours. The exposed model was comfortable during the daytime for a quarter of the time for the eastern orientation and a third of the time for the western orientation In the evenings, most of the hours were comfortable for the eastern orientation and two thirds for the western orientation.
- the single glazed, exposed and semi-exposed spaces, were comfortable for between a third and a half of the daytime periods and most of the evenings, the integral, single glazed spaces were comfortable for between a quarter and a third of these periods.

January, February, November and December :

- all the glazed spaces were virtually unusable during January and December, with a few hours in the exposed, double and low E glazed situations; showing the benefit of the larger areas of wall glazing, for east and west facing models. Up to a quarter of available hours usable in November and December, with increasing insulation properties of the glazing.

September and May :

- all the models, except the exposed, single and double glazed suffered discomfort due to high temperatures. Comfortable hours ranging fom a third to a half of available hours.

March, April and October

- comfortable hours between a half and three quarters of those available, with discomfort being caused by low temperatures. Some discomfort from high temperatures with increasing insulation value of the glazing.

Comparison of the annual space heating loads of the basic houses and the three house types with a heated or unheated glazed space

Conclusions which can be drawn from analysis of the annual space heating loads

Charts of the annual predicted space heating loads of the basic houses and the houses with a heated or unheated glazed space are included on the pages following these conclusions in Figures 4.18 - 4.21, organised by orientation. Tables of predicted heating loads, cost of heating and percentage increases or decreases on the space heating loads for the basic houses as a result of an unheated or heated glazed space are included in Appendix H.
As explained previously two basic house types are included for comparison, one of 132m^2, the second of 110m^2 total floor area.

Models with exposed glazed spaces compared to the 110m^2 basic house

For all orientations the addition of the **unheated** single glazed space decreases the heating load for the basic house by only a very small amount, the maximum being 4.9% in the north facing situation. Increasing the insulating properties of the glazing only has a very small effect in the unheated situation, the maximum being a reduction in the space heating load of 7.3% using low E glazing in the north facing situation
The addition of a **heated** single glazed space more than doubles the space heating load of the basic house for any orientation, with increases ranging from 102-117% depending on orientation.
The addition of a **heated** double glazed space increases the heating load of the basic house by approximately 48%-60% depending on orientation.
The addition of a **heated** low E glazed space increases the heating load of the basic house by approximately 24%-33% depending on orientation.

The predicted space heating costs for the north and south facing houses with heated glazed spaces are tabulated below. See also the notes after Table 4.03, regarding the results and after Table 4.04, regarding costs and assumptions.

Table 4.02 **The predicted cost of heating for the houses with north and south facing, exposed heated glazed spaces,**
corrected to the nearest pound

	House	Glazed space	Total	Basic 110m^2 house
north / single	£74	£103	£178	£82
north / double	£73	£58	£131	£82
north / low E	£72	£37	£109	£82
south / single	£74	£88	£163	£80
south / double	£73	£45	£118	£80
south / low E	£72	£26	£99	£80

Models with semi-exposed glazed spaces compared to the 110m^2 basic house

With reference to the results tabulated in Appendix H;
In the semi-exposed situation the predicted space heating loads for the houses with **unheated** glazed spaces are very similar to those for the 110m^2 basic house of the same orientation. Those for a house with a single glazed space being up to 2% greater and those for a house with a low E glazed space being generally 3.5 % lower, 6% lower for the south facing situation.
The incorporation of a semi-exposed **heated** single glazed space results in increases of 70% - 89% on the space heating load of the basic 110m^2 house depending on orientation.
The incorporation of a semi-exposed **heated** double glazed space results in increases of 33% - 51% on the space heating load of the basic 110m^2 house depending on orientation.
The incorporation of a semi-exposed **heated** low E glazed space results in increases of 14% - 30% on the space heating load of the basic 110m^2 house depending on orientation.
The predicted space heating costs for the north and south facing houses with heated glazed spaces are tabulated below. See also the notes after Table 4.04 regarding costs and assumptions.

Table 4.03 **The predicted cost of heating for the houses with north and south facing, semi-exposed heated glazed spaces,**
corrected to the nearest pound

	House	Glazed space	Total	Basic 110m^2 house
north / single	£78	£77	£155	£82
north / double	£76	£48	£124	£82
north / low E	£75	£32	£106	£82
south / single	£76	£60	£136	£80
south / double	£74	£32	£106	£80
south / low E	£73	£19	£92	£80

Notes on the results in Tables 4.02 and 4.03

Care was taken in the preparation of the house models to ensure that the areas of glazing on the north and south facades were close in order to negate the effect of solar gain, through the glazing, on the house heating load when the models were rotated. In this way the orientation of the the house has only a marginal effect on the house heating load as indicated by the results in Tables 4.02 and 4.03 and any reduction in the house heating load is predominantly due to the effect of the glazed space. The difference in the heating costs in the case of the basic houses is due to the effect of the exposure of the patio doors.

Models with integral glazed spaces

The effect of the integration of a glazed space into the building envelope can be assessed in two ways;

- comparison with the basic 110m^2 house heating loads for the unheated glazed space situation
- comparison with the basic 132m^2 house heating load in the heated glazed space situation.

Referring to the results tabulated in Appendix H;
For most orientations and glazing types the space heating load for 110m^2 of accommodation surrounding an **unheated** glazed space is slightly greater, [up to 8.5%] than that for the basic 110m^2 house. This is due to the additional heat loss through the enlarged external envelope. The **unheated**, integral south facing, low E glazed space provides slight savings of 5%, when compared to the basic 110m^2 house.

Comparing the space heating load of the house with a **heated**, integral glazed space against that for an identical volume enclosed in standard construction, and with identical heating requirements [the 132m^2 basic model] slight savings, are indicated for the low E glazed east and west facing model [4% and 6% respectively] and for the south facing, double and low E glazed models [3% and 13% respectively]. Although these indicate the possibilities for the reduction of space heating loads by the effect of solar gain through large areas of glazing the savings are only marginal and could easily be reversed under different patterns of occupancy, heating regime, ventilation and incidental gains from equipment.
For the other combinations of orientation and glazing, increases in the space heating load of 4% - 31% are predicted when compared to the 132m^2 basic house heating load.

The heating costs for the north and south facing situations are tabulated below. See also the notes after Table 4.04 regarding costs and assumptions

Table 4.04 **The predicted cost of heating for the houses with north and south facing, integral heated glazed spaces,**
corrected to the nearest pound

	House	Glazed space	Total	Basic 132m^2 house
north / single	£82	£52	£134	£102
north / double	£80	£36	£115	£102
north / low E	£78	£25	£103	£102
south / single	£78	£33	£112	£98
south / double	£75	£20	£95	£98
south / low E	£73	£12	£85	£98

Comparison of space heating loads for the basic houses

Comparison of the space heating loads for the basic houses as shown in Tables 4.03 and 4.04 indicate that the space heating load of the 132m^2 north facing basic house is 24% greater than that of the 110 m^2 north facing basic house even though the increase in floor area is only 20%. This anomoly is accounted for by the fact that the absolute value for occupancy and internal gains were kept constant for the two models as explained in the description of the setting up of the basic house models. Similar effects are seen for the basic houses with other orientations. See also Appendix H

Notes and assumptions on the space heating loads and costs

As stated previously, the glazed space was operating in buffer mode, and no attempt was made to transfer warm air from the glazed space into the rooms of the house during the simulations.

Space heating costs are based on the assumption that the house was heated by a gas fired, hot water radiator system and that This system was also used in the heated glazed spaces. The costs are calculated using the June 1995 delivered price for the supply of gas, 1.54 pence per kWh [including VAT at 8%], but do not include standing charges. Neither the heating loads nor the costs include boiler losses.

The space heating loads for the glazed spaces

The results shown below and in Appendix H indicate that the importance of orientation increases with better insulation of the glazing..
For the **north facing integral** glazed space;
changing from single to lowE glazing reduces the heating load by 52%
For the **south facing integral** glazed space;
changing from single to lowE glazing reduces the heating load by 64%
For the **north facing exposed** glazed space;
changing from single to lowE glazing reduces the heating load by 64%
For the **south facing exposed** glazed space;
changing from single to lowE glazing reduces the heating load by 70%

The results also show that the importance of integration decreases with better insulation of the glazing
For the **north facing single** glazed space,
moving from exposed to integral reduces the heating load by 50%
For the **north facing low E** glazed space,
moving from exposed to integral reduces the heating load by 32%
For the **south facing single** glazed space,
moving from exposed to integral reduces the heating load by 62%
For the **south facing low E** glazed space,
moving from exposed to integral reduces the heating load by 54%

Table 4.05 **Heating loads and costs for the north and south facing two storey glazed spaces**

	Integral		Semi-exposed		Exposed	
	heating load kWhs	cost of heating	heating load kWhs	cost of heating	heating load kWhs	cost of heating
north / single	3357	£52	5014	£77	6698	£103
north / double	2312	£36	3090	£48	3756	£58
north / low E	1621	£25	2062	£32	2391	£37
south / single	2175	£33	3878	£60	5726	£88
south / double	1288	£20	2083	£32	2907	£45
south / low E	811	£12	1254	£19	1711	£26

The advantages of using low E glazing, in reducing the heating costs, become more apparent with increasing exposure of the glazed space and therefore, increase in the area of glazing. However the approximate costs for the glazing materials included in Appendix I indicate the comparatively high cost of low E glazing, which could discourage potential users.

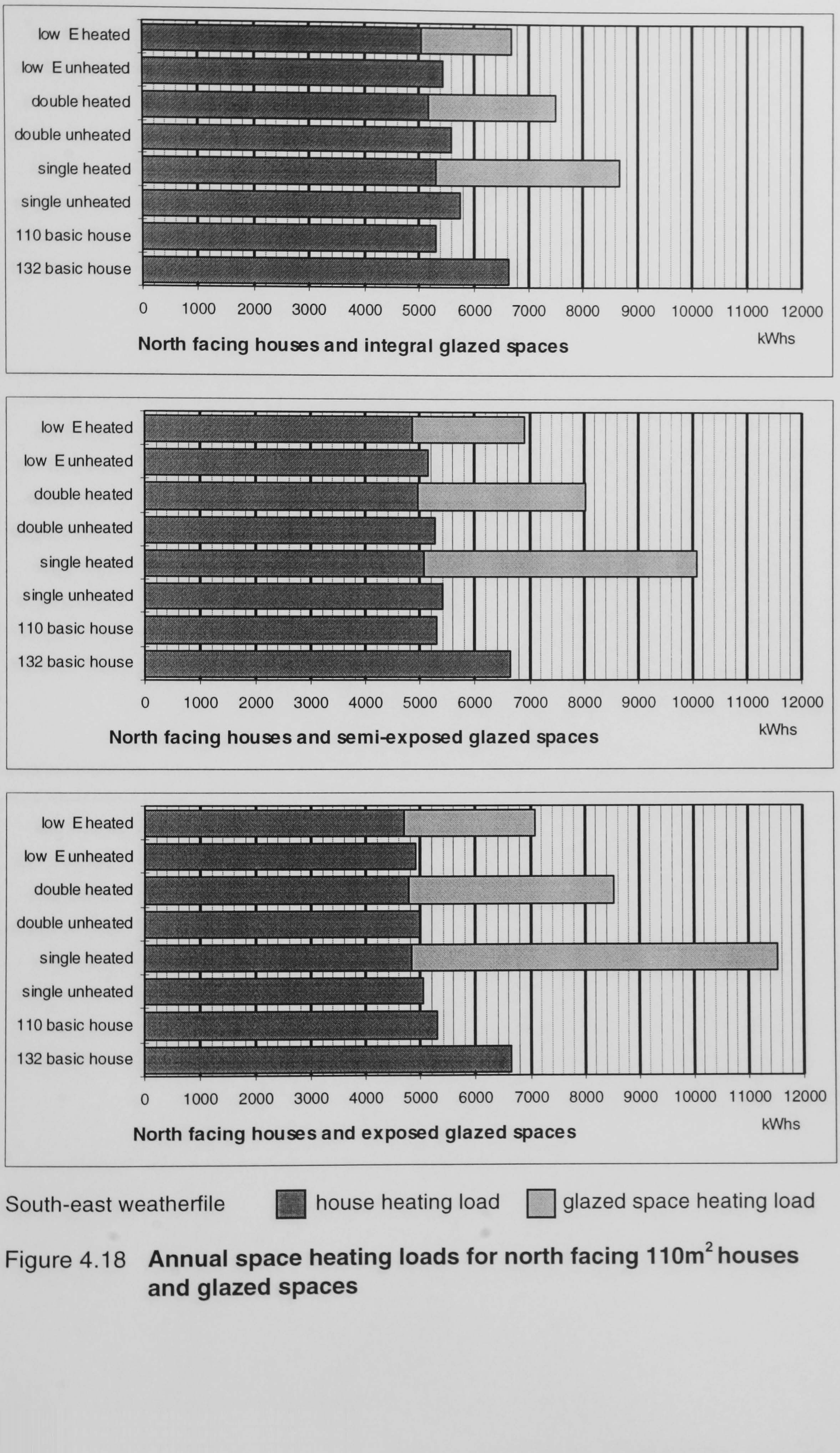


Figure 4.18 **Annual space heating loads for north facing 110m^2 houses and glazed spaces**

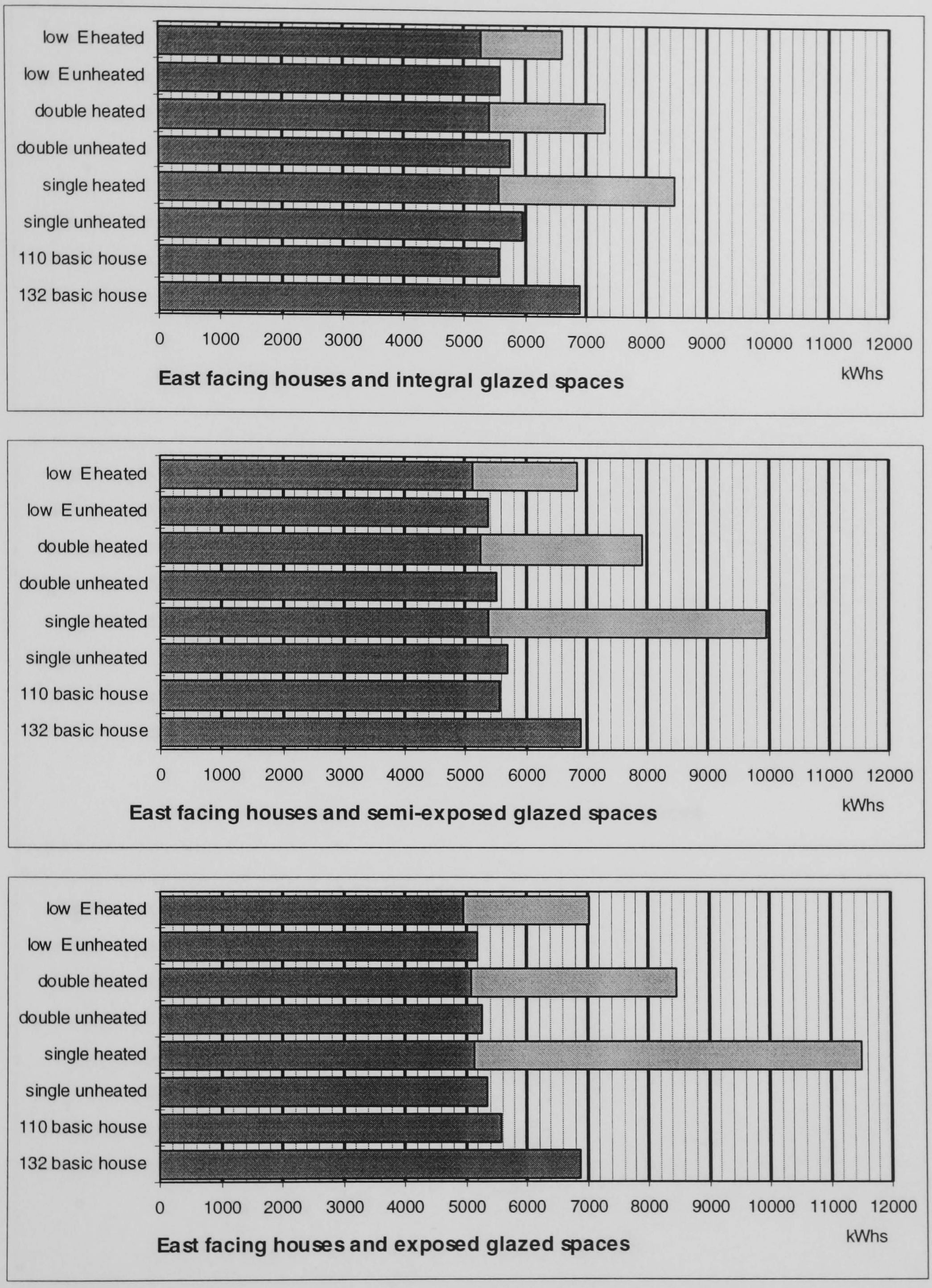


Figure 4.19 **Annual space heating loads for east facing 110m^2 houses and glazed spaces**

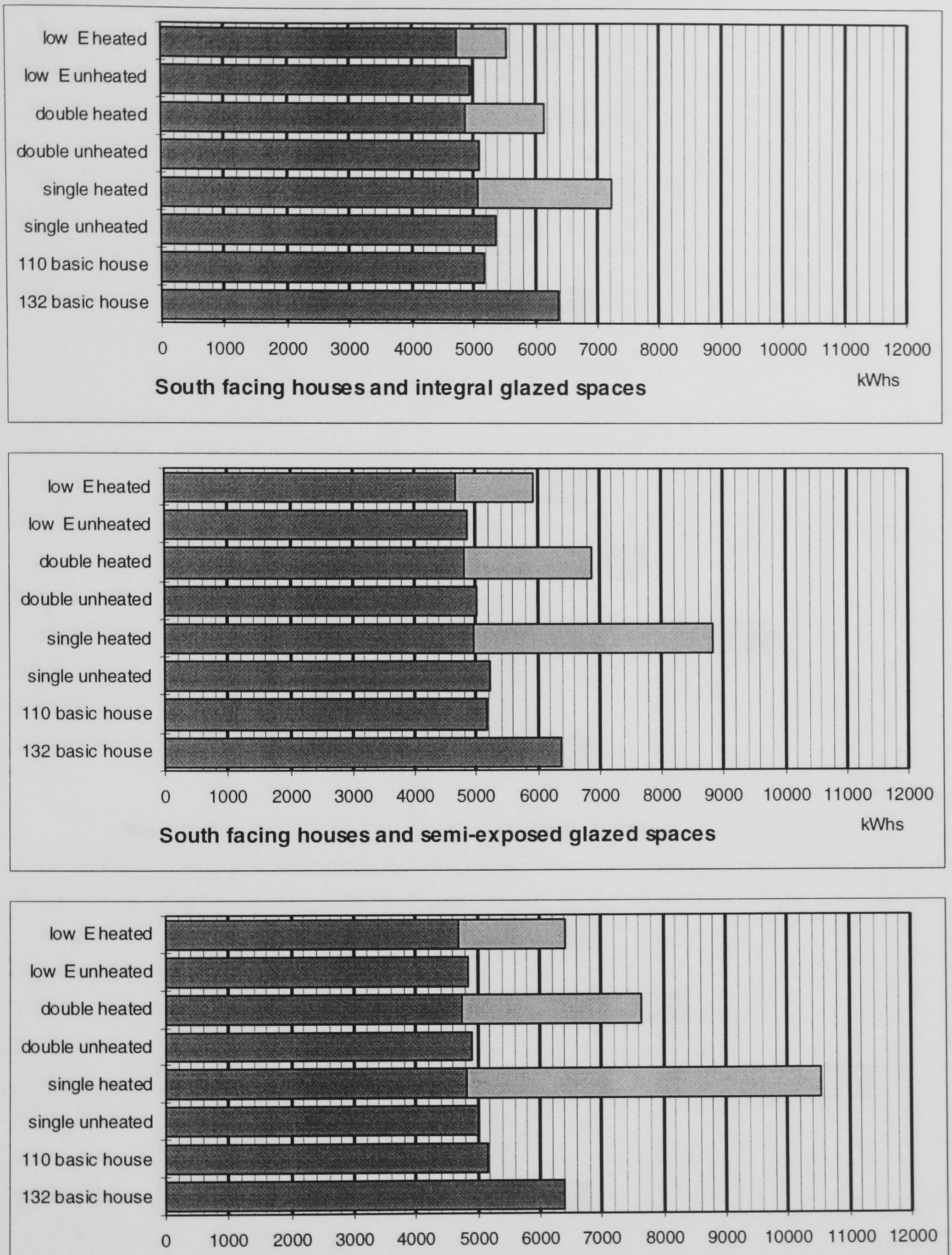
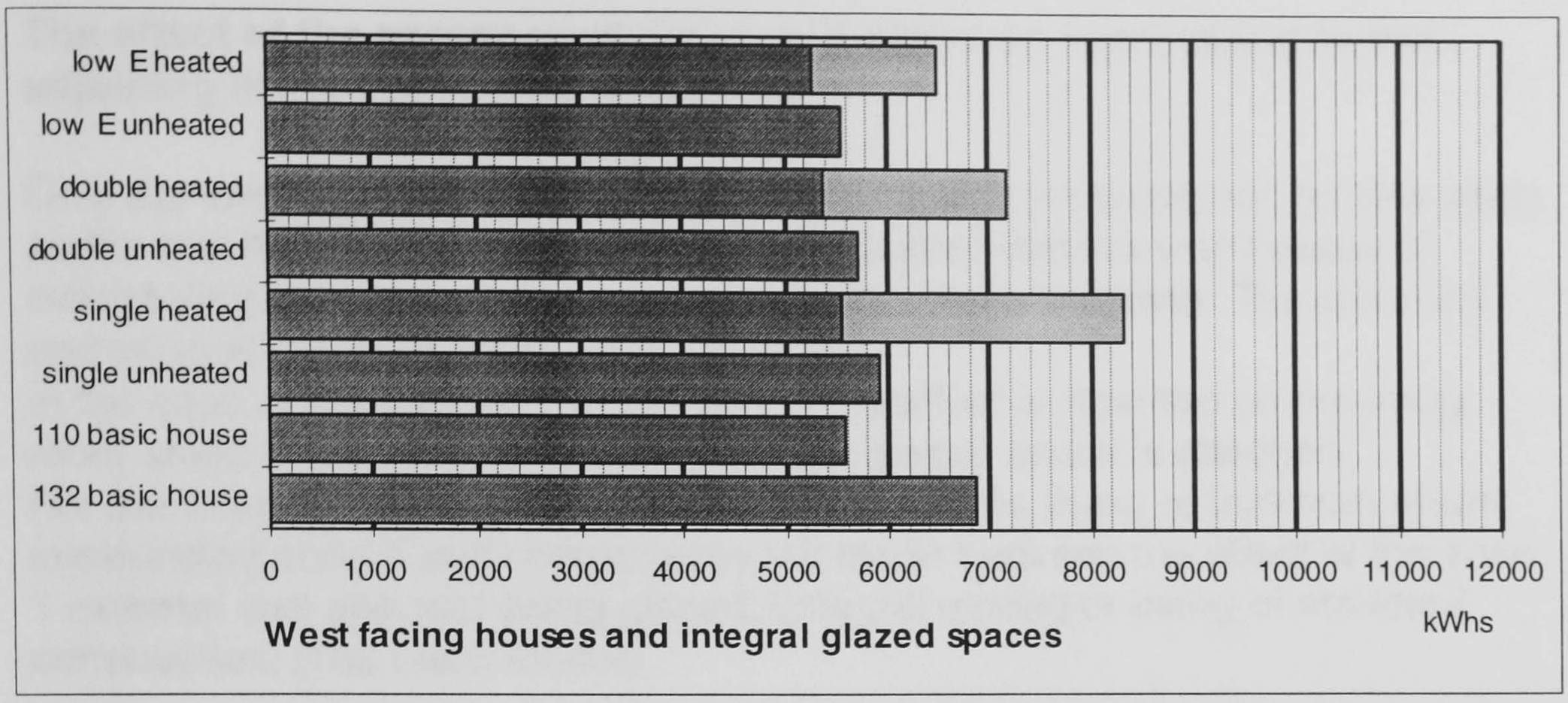


Figure 4.20 **Annual space heating loads for south facing 110m^2 houses and glazed spaces**



South-east weatherfile ■ house heating load □ glazed space heating load

Figure 4.21 **Annual space heating loads for west facing 110m^2 houses and glazed spaces**

The effect of the presence of the glazed space on overheating in the adjoining living rooms and bedrooms

Only the low E glazed, south facing models have been presented for this study as the results of the thermal simulations indicated that the worst cases of overheating occurred with this type of glazing and orientation. The exposed and integral situations are presented below.
In the case of the exposed glazed space the effect is reported on the living room areas or bedroom areas to which the glazed space is attached.
For the integral situation the effect is reported in the living or bedroom areas surrounding zone 1 and comparisons are made between the effect of the zone 1 external wall and roof being glazed, [integral model] or being of standard construction, [132 basic model].

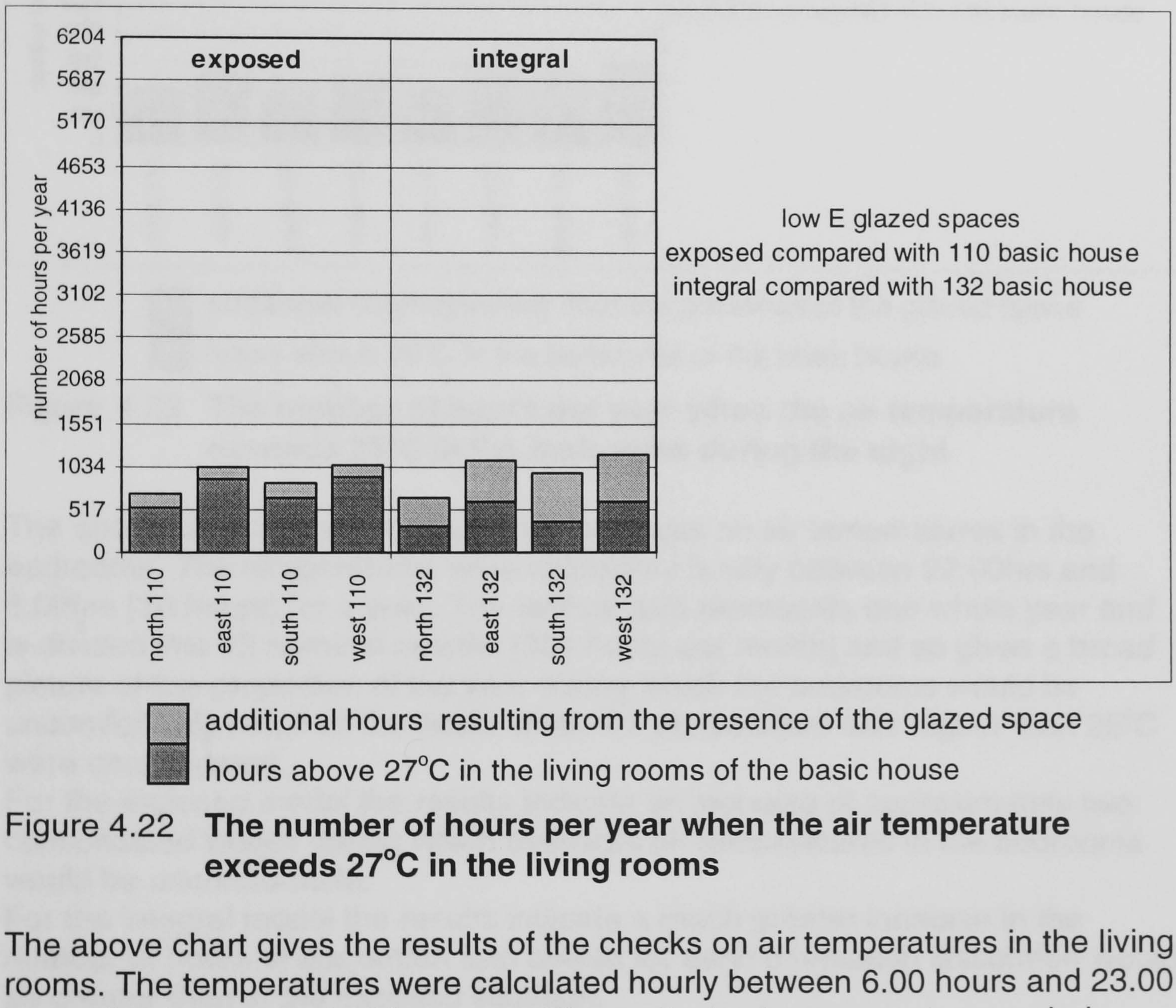


Figure 4.22 **The number of hours per year when the air temperature exceeds 27°C in the living rooms**

The above chart gives the results of the checks on air temperatures in the living rooms. The temperatures were calculated hourly between 6.00 hours and 23.00 hours, [17 hours per day] for a year. The vertical axis represents one whole year and is divided into 12 nominal months [517 hours per month] and so gives a broad picture of the proportion of the year during which the living rooms would be uncomfortably hot, if all the hours when the temperature was higher than 27°C were consolidated.

Figure 4.22 shows that the addition of a two storey, exposed, unventilated glazed space, will increase the overheating experienced in the living rooms by approximately ten consolidated [17 hour] days, for all orientations.
In the case of the integral glazed space, glazing the wall and roof will approximately double the hours of discomfort in the rooms surrounding the space. However the overall number of uncomfortable hours for each orientation is similar in both the integral and exposed situations.

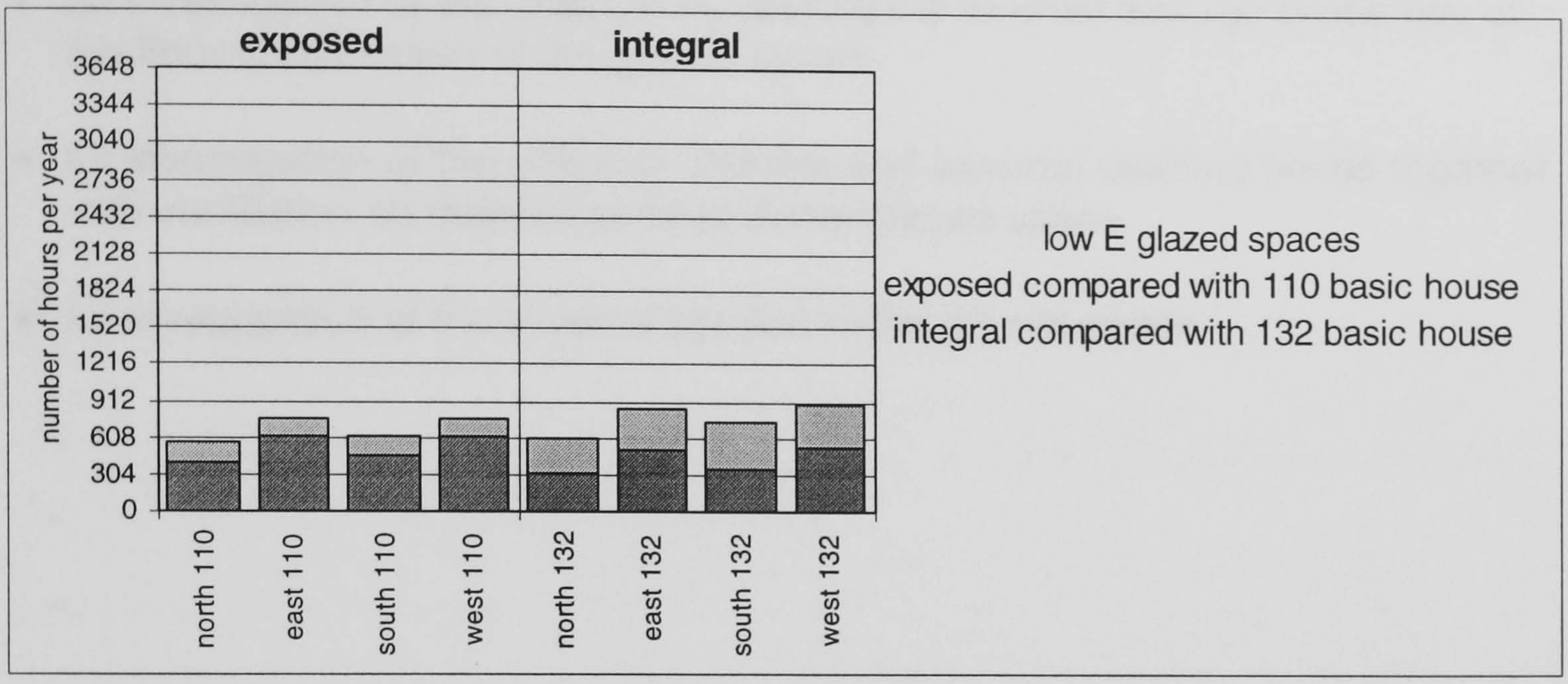


Figure 4.23 **The number of hours per year when the air temperature exceeds 25°C in the bedrooms during the night**

The above chart gives the results of the checks on air temperatures in the bedrooms. The temperatures were calculated hourly between 22.00hrs and 8.00hrs [10 hours] for a year. The vertical axis represents one whole year and is divided into 12 nominal months [304 hours per month] and so gives a broad picture of the proportion of the year during which the bedrooms would be uncomfortably hot, if all the hours when the temperature was higher than 25°C were consolidated.
For the exposed model the results indicate an increase of approximately two consolidated weeks during which overnight air temperatures in the bedrooms would be uncomfortable.
For the integral model the results indicate a much greater increase in the number of hours of discomfort and overall for each orientation discomfort would be greater than in the exposed situation.
The results indicate that bedrooms should be ventilated directly to outside rather than solely through the glazed space.

Further Studies

Four further studies were then undertaken on the two storey glazed space;

- the use of the buoyancy effect to increase ventilation and reduce high temperatures in the glazed space

- an investigation of the effect of increasing the thermal storage properties of the floor construction of the glazed space

- an investigation of the effect of internal and external shading blinds together with ventilation on thermal comfort in the glazed space

- an investigation of the thermal comfort in the glazed space

4.04 The Use of the Buoyancy Effect to Increase Ventilation and Reduce High Temperatures in the Glazed Spaces

The investigation into the effect of buoyancy driven ventilation in the single storey glazed space model indicated that this method could provide a useful mechanism for the reduction of high temperatures in glazed spaces. The procedure was therefore applied to several of the two storey glazed space models in order to test the effect of buoyancy driven ventilation in different situations as follows;

- integral and exposed, south facing, low E glazed
- integral, south facing, double glazed
- integral and exposed, north facing, low E glazed

Integral and Exposed, South Facing, Low E Glazed Models

This combination of orientation and glazing gave rise to the longest number of hours of discomfort due to high resultant temperatures, as indicated by the results of the initial simulations. The integral and exposed situations also covered the two extremes of exposure and glazing area.

For the exposed model a similar approach to the area and positioning of ventilators was taken as for the study for the single storey glazed space; two alternative areas for high and low level ventilators, 0.15m^2 and 0.3m^2 positioned along the sides of the glazed space.

For the integral model, the areas were the same but the ventilators had to be positioned on the front wall, as this was the only exposed vertical surface. A different correlation was used for this situation; openings on one wall only, [CIBSE Guide, Section A4, 1986], but the iterative process remained the same. The positioning of the ventilators for the exposed and integral models is shown in Figures 4.24 and 4.25 on the following pages.

The iterative process and one day thermal simulations

The iterative process for the simulation of buoyancy driven ventilation was worked through twice for each model using the alternative areas for high and low level openings; 0.15m^2 and 0.3m^2. The days chosen for the simulations were again Day 201, with mostly diffuse solar radiation, and Day 180, with high levels of direct and diffuse radiation, as used for the single storey glazed space study. Day 201 has wind speeds varying from 0.9 to 7.6 metres/second and Day 180 has wind speeds varying from 2.2 to 6.7 metres/second. An additional day, Day 184 with a maximum wind speed of only 2.7 metres/second, during the daytime and evening periods, was therefore also used in order to test the effect of wind speed on the ventilation process. Day 184 is also a day of continuous high levels of direct and diffuse solar radiation with a maximum external air temperature of 22.4°C occurring at 16.00hrs GMT.

[See Appendix F]

The air change rates achieved at the end of the iterative processes are shown in Tables 4.06 and 4.07

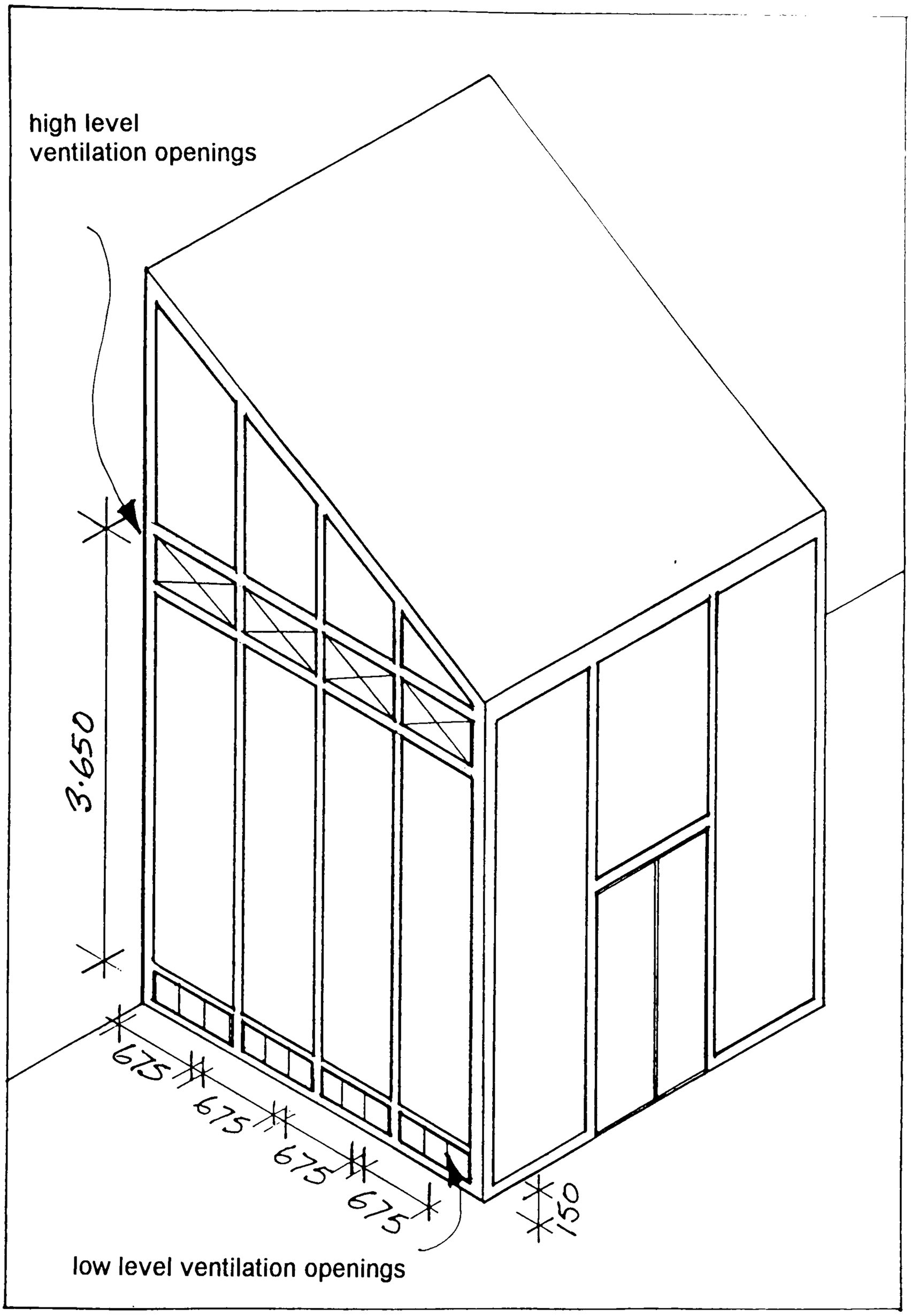


Figure 4.24 **The incorporation of high and low level ventilation openings into the exposed glazed space**

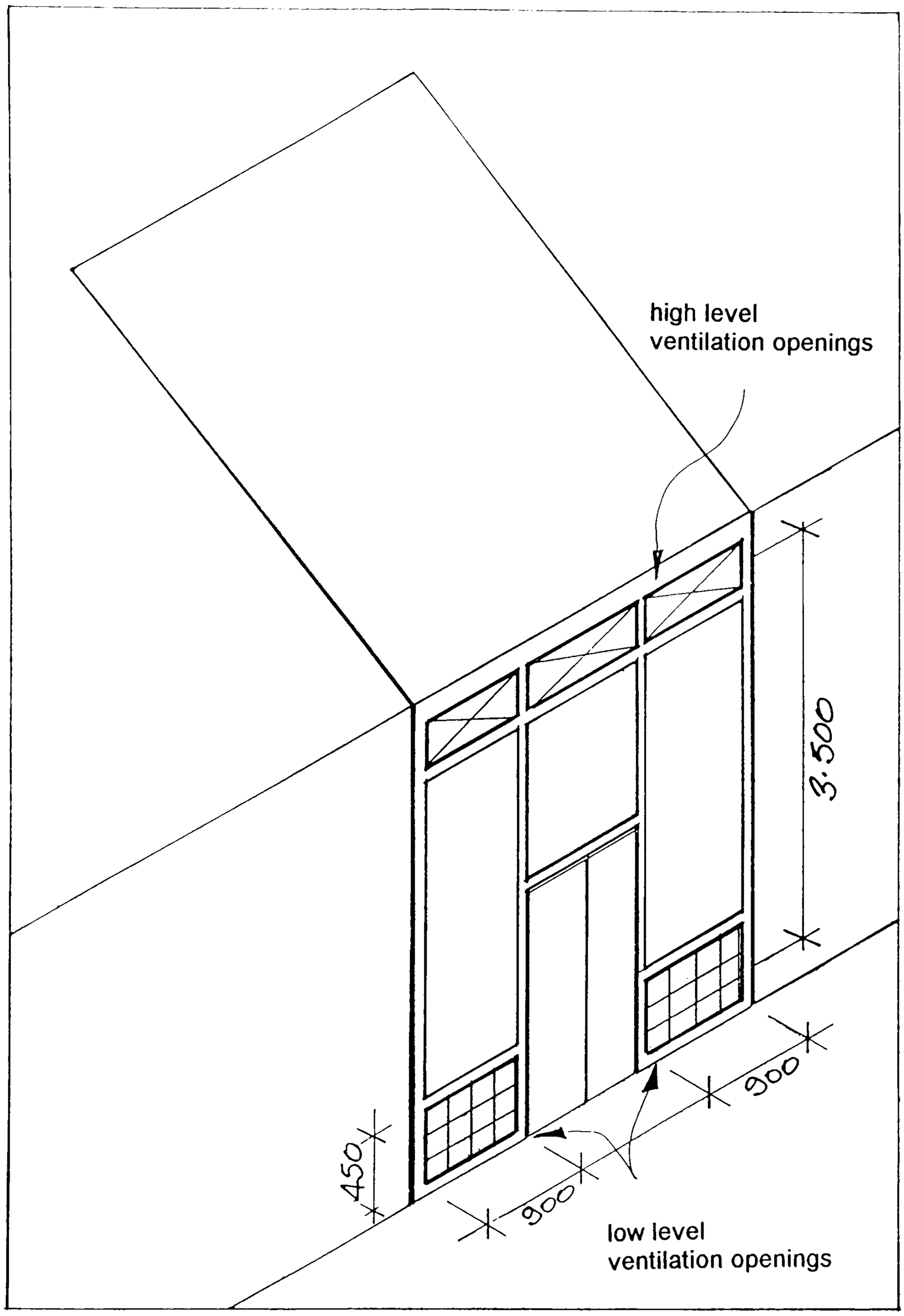


Figure 4.25 **The incorporation of high and low level ventilation openings into the integral glazed space**

Exposed, south facing, low E glazed

Table 4.06 **The air change rates achieved at the end of the iterative process for Day 201 and Day 180**

	0.15m^2 openings		0.3m^2 openings	
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h
0.00-8.00hrs	4.5	4.5	7.8	7.9
8.00-1200hrs	5.7	7.4	10.1	12.9
12.00-16.00hrs	5.7	7.7	10.1	13.2
16.00-20.00hrs	4.6	5.7	7.9	9.8
20.00-24.00hrs	4.6	4.6	7.9	7.8

Integral, south facing, low E glazed

Table 4.07 **The air change rates achieved at the end of the iterative process for Day 201, Day 180 and Day 184**

	0.15m^2 openings		0.3m^2 openings		
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h	Day 184 ac/h
0.00-8.00hrs	4.9	4.8	8.5	8.3	9.8
8.00-1200hrs	5.2	6.4	9.1	11.3	11.3
12.00-16.00hrs	5.2	6.3	9.1	11.0	11.9
16.00-20.00hrs	5.0	5.5	8.7	9.5	10.5
20.00-24.00hrs	5.0	5.5	8.7	9.5	10.2

The above tables show that the conditions on Day 201 generally promote lower air change rates than those on Days 180 and 184. Although the external air temperatures on Day 180 and 184 are higher than those on Day 201, the internal temperatures also rise to high levels due to the increased solar gain, therefore promoting higher air change rates.

The simulation results for internal air temperature and resultant temperature using these air change rates in both models, on Days 201 and 180 are shown in Figures 4.26-4.33. The internal air and resultant temperatures occurring when there is no ventilation, only infiltration at 0.85 ac/h, together with the external air temperature are also included for comparison.

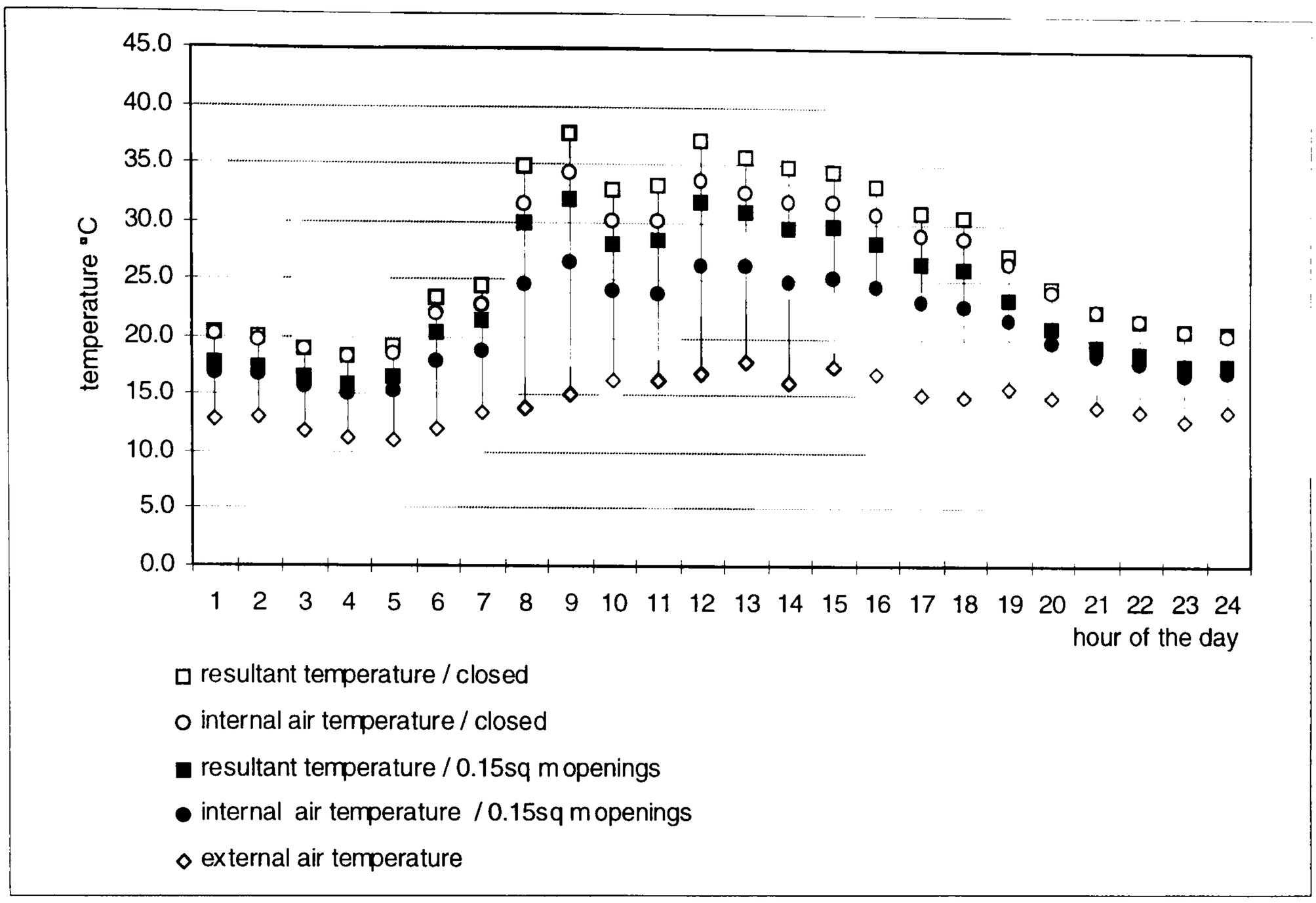


Figure 4.26 **Temperature reduction caused by openings of area 0.15m^2 in the exposed, south facing, low E, glazed space, Day 201**

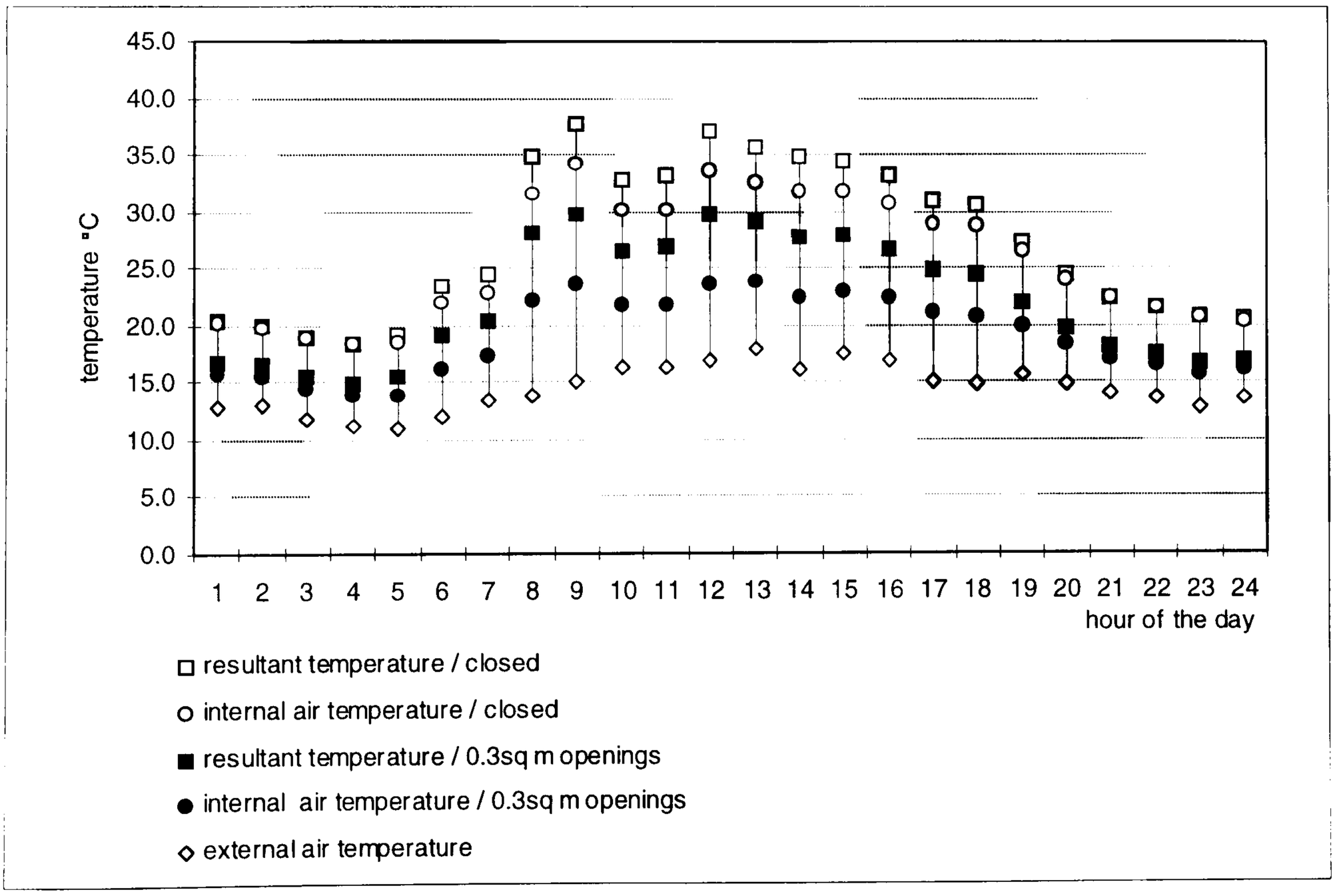


Figure 4.27 **Temperature reduction caused by openings of area 0.3m^2 in the exposed, south facing, low E glazed space, Day 201**

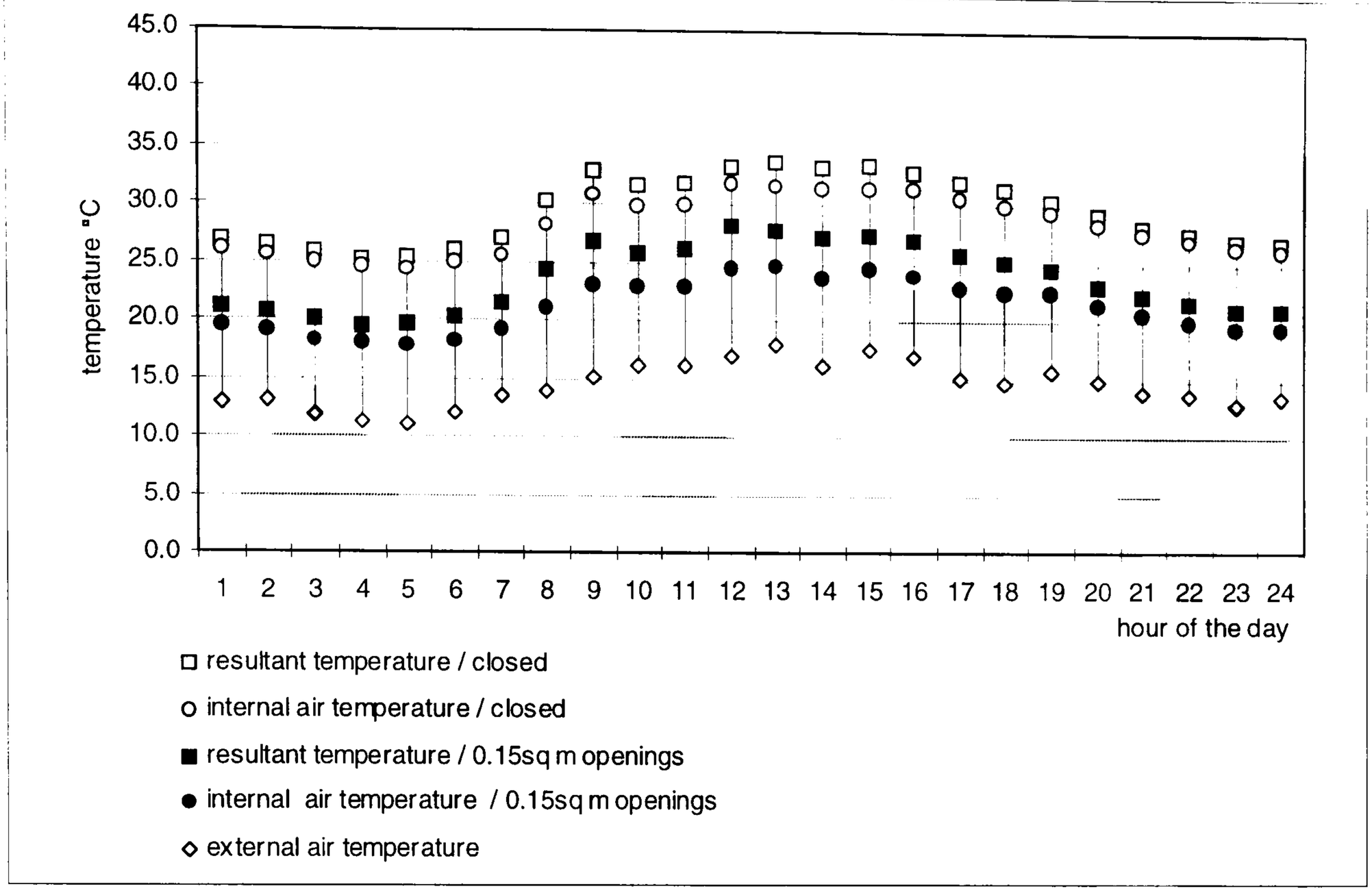


Figure 4.28 **Temperature reduction caused by openings of area 0.15m^2 in the integral, south facing, low E glazed space, Day 201**

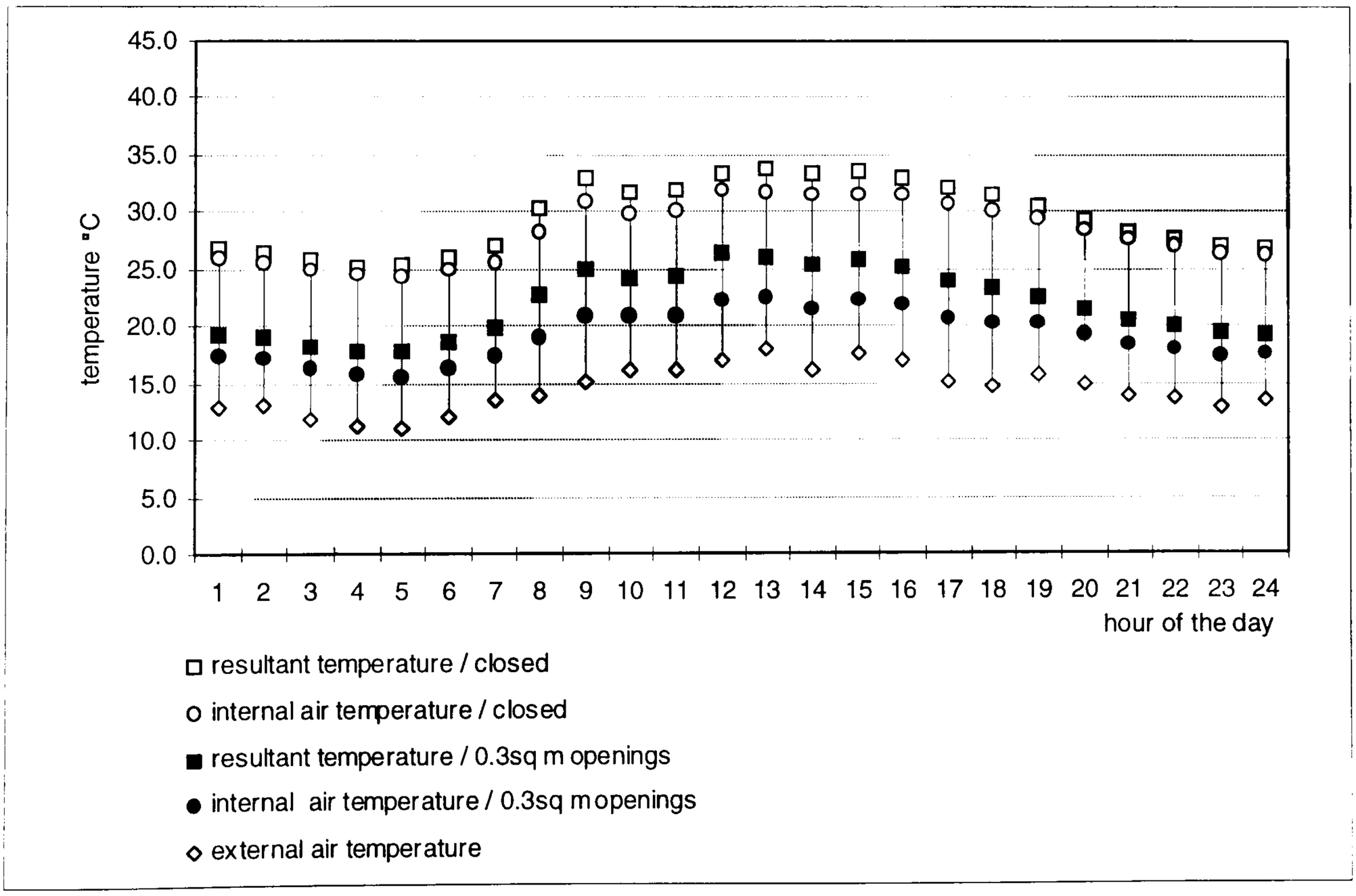


Figure 4.29 **Temperature reduction caused by openings of area 0.3m^2 in the integral, south facing, low E glazed space, Day 201**

Analysis of the results for Day 201

Exposed, south facing, low E glazed space

Figures 4.26 and 4.27, for Day 201, indicate that in the unventilated situation the resultant temperature, reached a maximum value of 37.6°C and the air temperature reached a maximum value of 34.2°C.
Openings of 0.15m^2 reduced these to 32°C and 26.6°C respectively.
Openings of 0.3m^2 reduced them to 29.8°C and 23.7°C respectively.
Without ventilation there were 3 hours, during the daytime and evening, when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 6 hours and openings of 0.3m^2 increased this figure to 9 hours.

Integral south facing, low E glazed space

Figures 4.28 and 4.29, for Day 201, indicate that in the unventilated situation resultant temperature, reached a maximum value of 34.4°C and the air temperature reached a maximum value of 31.9°C.
Openings of 0.15m^2 reduced these to 28.3°C and 24.7°C respectively and openings of 0.3m^2 reduced these to 26.4°C and 22.6°C respectively.
Without ventilation there were no hours, during the daytime and evening, when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 9 hours and openings of 0.3m^2 brought the resultant temperature down below 27°C for the whole 24 hour period.

Comparison of the results for the integral and exposed glazed spaces

The integral glazed space which has three solid walls, provides a much greater area of solid construction, with the potential for heat storage, than the exposed space which has only one solid wall. [The thermal storage provide by the floor construction is common to both models]. The smaller area of external glazing in the integral glazed space also results in less solar radiation entering the space than in the exposed model.
Without ventilation, the resultant temperature in the integral space remained above 27°C for a much longer period than in the exposed space. However the peak temperatures reached in the integral space were several degrees lower than in the exposed space.
Ventilation was able reduce the resultant temperature within the integral space to below 27°C for the whole of the daytime and evening periods but did not achieve a similar effect in the exposed space.
This indicates that in certain weather conditions such as low levels of direct solar gain, as on day 201, ventilation will be able to reduce temperatures in an integral glazed space to more comfortable levels for longer periods than in an exposed glazed space.

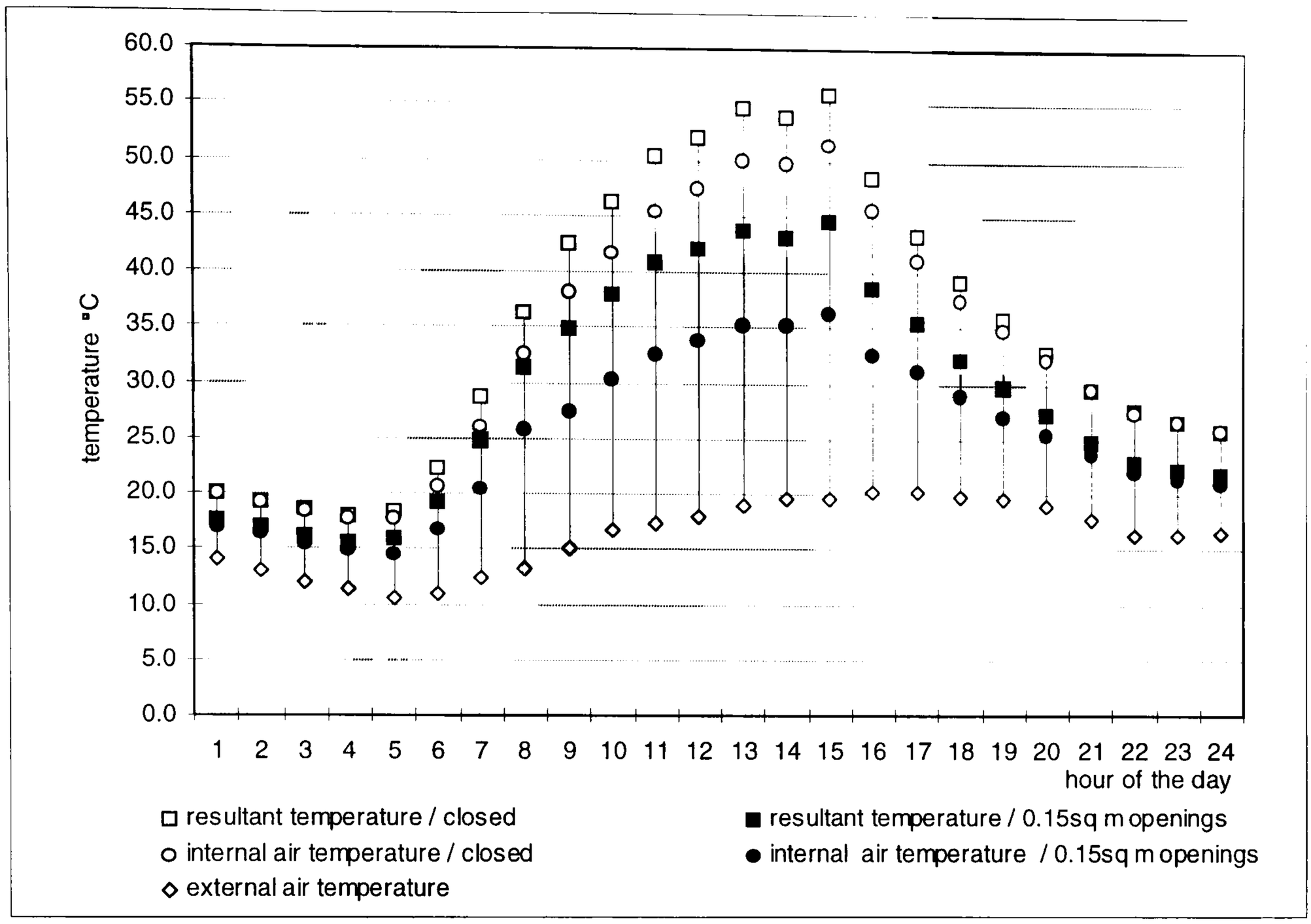


Figure 4.30 **Temperature reduction caused by openings of area 0.15m^2 in the exposed, south facing, low E glazed space, Day 180**

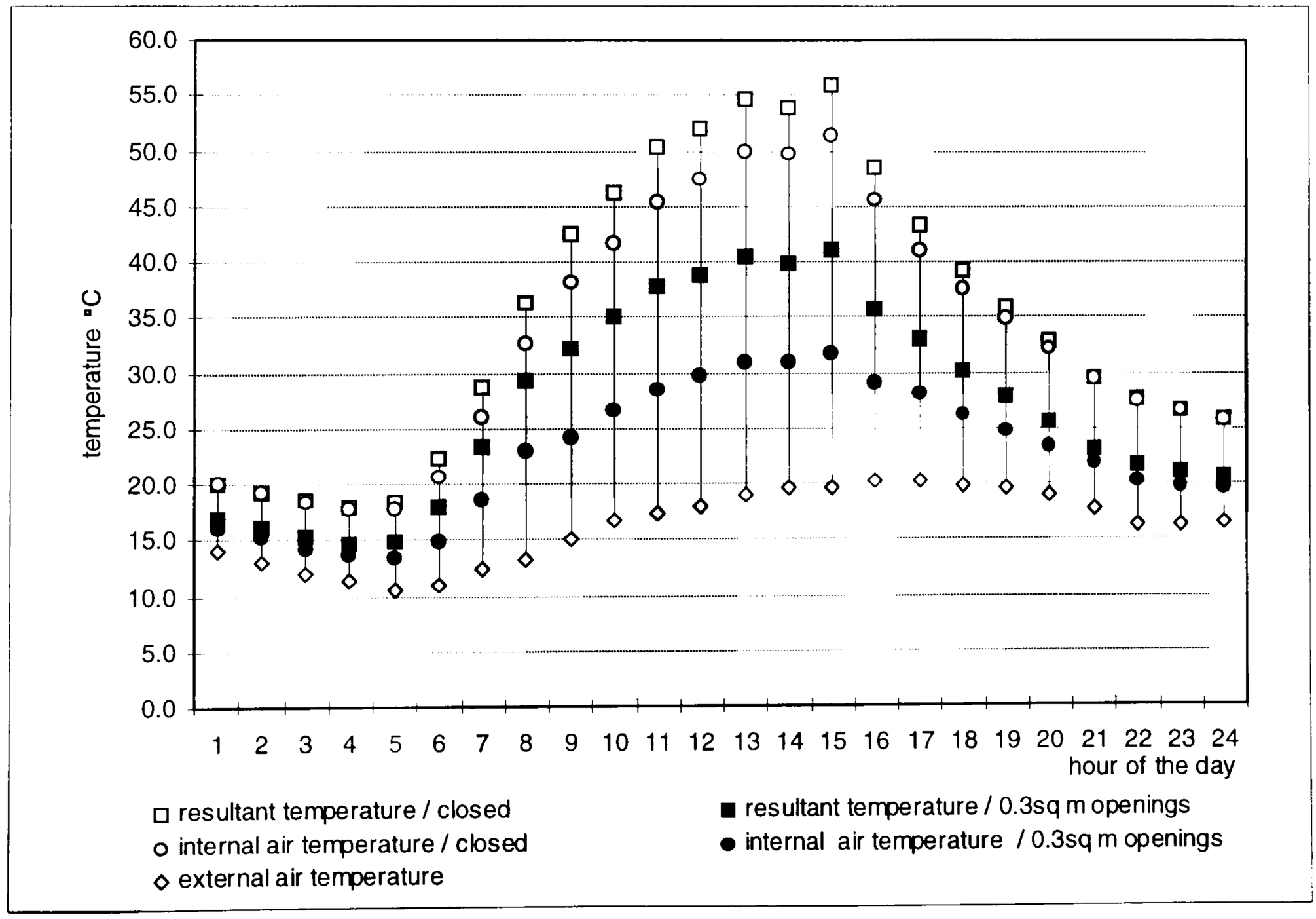


Figure 4.31 **Temperature reduction caused by openings of area 0.3m^2 in the exposed, south facing, low E glazed space, Day 180**

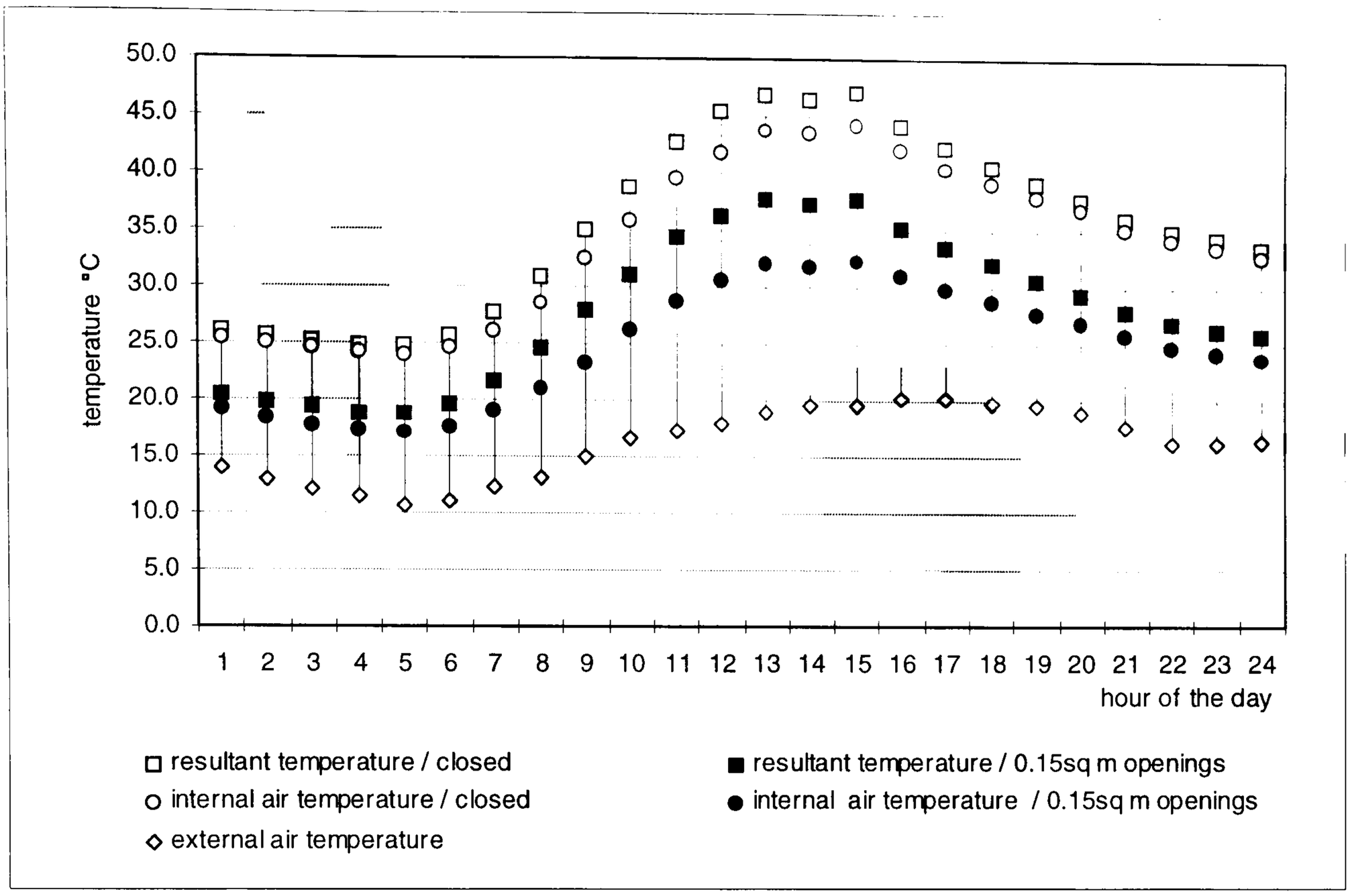


Figure 4.32 **Temperature reduction caused by openings of area 0.15m^2 in the integral, south facing, low E glazed space, Day 180**

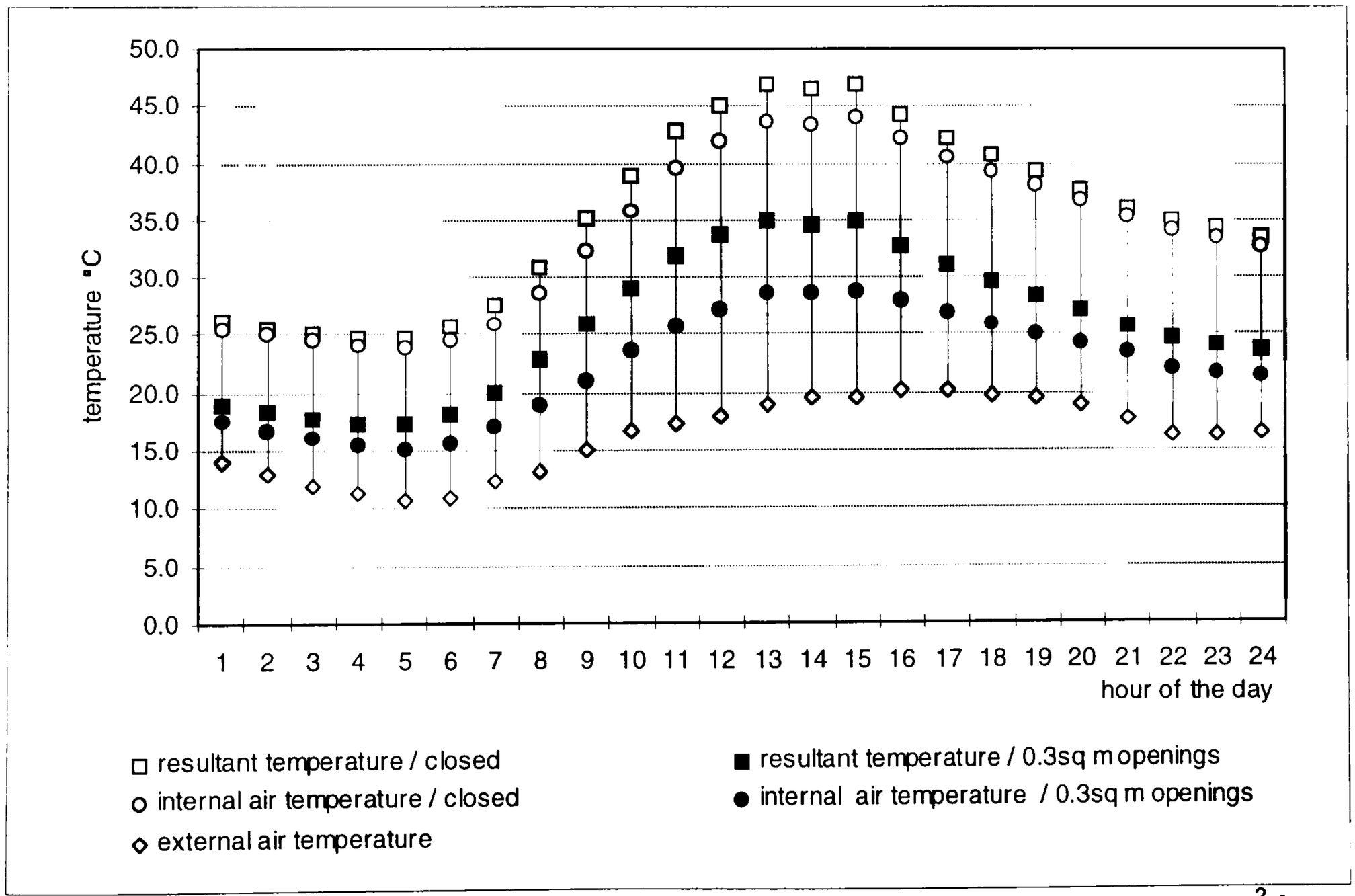


Figure 4.33 **Temperature reduction caused by openings of area 0.3m^2 in the integral, south facing, low E glazed space, Day 180**

Analysis of the results for Day 180

Exposed, south facing, low E glazed space

Figures 4.30 and 4.31, for Day 180, indicate that in the unventilated situation the resultant temperature, reached a maximum value of 55.9°C and the air temperature reached a maximum value of 51.4°C.
Openings of 0.15m^2 reduced these to 44.5°C and 36.2°C respectively.
Openings of 0.3m^2 reduced them to 41°C and 31.7°C respectively.
Without ventilation, during the day and evening, there was only 1 hour when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 3 hours and openings of 0.3m^2 increased this figure to 4 hours.

Integral south facing, low E glazed space

Figures 4.32 and 4.33, again for Day 180, indicate that in the unventilated situation resultant temperature, reached a maximum value of 47°C and the air temperature reached a maximum value of 44.1°C.
Openings of 0.15m^2 reduced these to 37.7°C and 32.3°C respectively and openings of 0.3m^2 reduced these to 35.0°C and 28.8°C respectively.
Without ventilation, during the day and evening, there were no hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 3 hours and openings of 0.3m^2 increased this figure to 6 hours.

Comparison of integral and exposed glazed spaces on Day 180 with those on Day 201

Comparison of the results for Day 180 and Day 201 indicates that although higher air change rates are generated on Day 180 [see Tables 4.05 and 4.06] the resulting ventilation is insufficient to reduce the higher temperatures to comfortable levels to the same extent as on Day 201. The external air temperatures on Day 180 are also higher than on Day 201 and therefore the air has less of a cooling effect when introduced into the glazed spaces.

Estimating the effect of buoyancy driven ventilation during July

In order to investigate the possible effect of buoyancy driven ventilation occurring over a longer period than one day, the figures for the air change rates obtained for Day 201, were put into the internal conditions data sheet for the glazed space for the whole of the month of July and the thermal simulation re-run for the year. The hours for resultant temperatures above 30°C and 27°C and below 16°C and 12°C were obtained from the simulation results via the report generator program. Figure 4.34 overleaf illustrates the results for the July period together with a chart of the results of the initial simulation, [ventilators closed] for comparison.
The charts indicate a substantial reduction in the hours of overheating in July, for the integral glazed space but less of a reduction in the exposed situation particularly with the use of 0.3m^2 ventilation openings. For the exposed glazed space resultant temperatures fell within the comfortable range for 28% of the daytime hours and 74% of the evening hours. For the integral glazed space,

resultant temperatures fell within the comfortable range for 45% of the daytime hours and 68% of the evening hours.
However, Day 201 was a mainly overcast day and higher air change rates could be expected on days of bright sunshine, as indicated by the simulations for Day 180 and Day 184. In reality therefore the number of comfortable hours in July could possibly be higher than those indicated below.

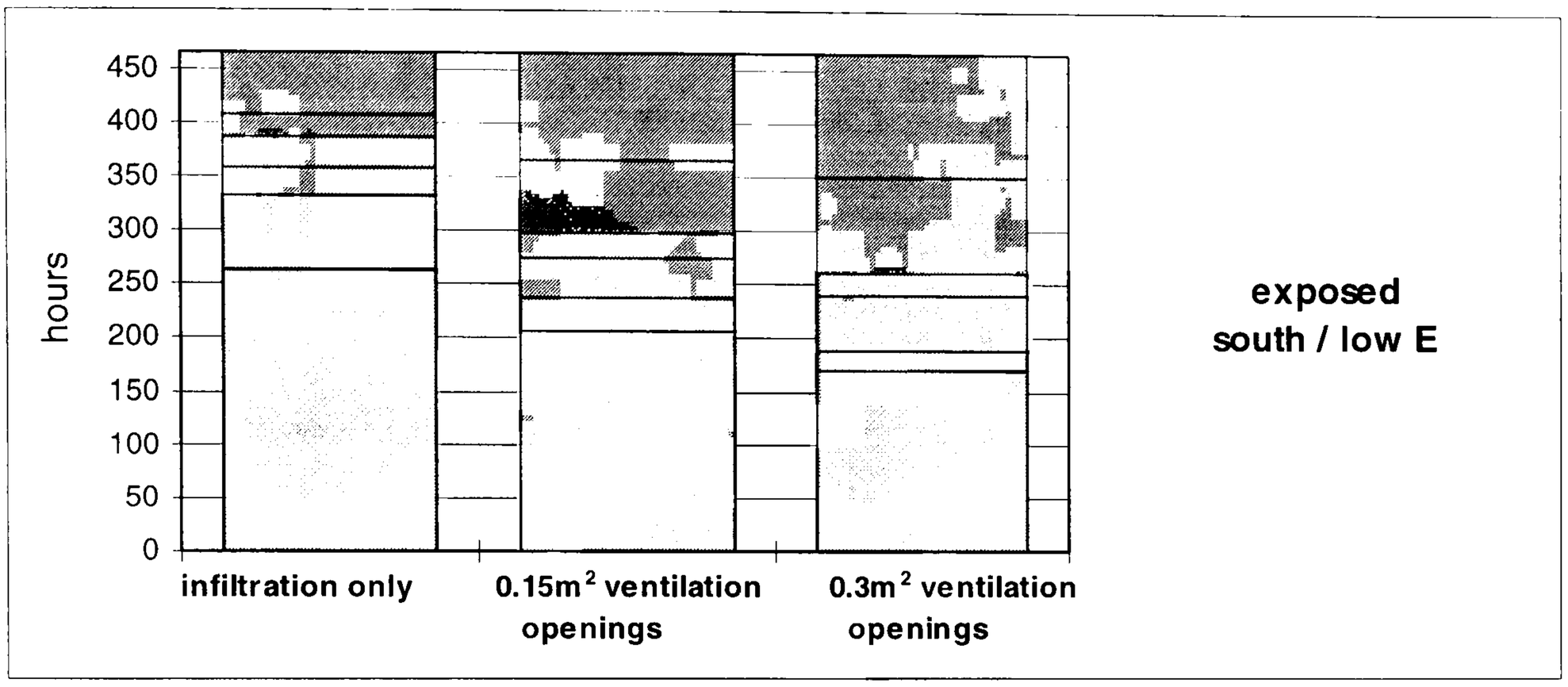


Figure 4.34 **The effect of increasing ventilation rates during July in the exposed and integral, south facing low E glazed spaces**

The Integral, South Facing, Double Glazed Model

In order to investigate the effect of a different type of glazing on buoyancy driven ventilation the iterative process was worked through for Day 201 and Day 180 for the integral, south facing double glazed model.

Table 4.08 **The air change rates achieved at the end of the iterative process for Day 201, and Day 180**

	0.15m^2 openings		0.3m^2 openings	
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h
0.00-8.00hrs	4.7	4.7	8.3	8.1
8.00-1200hrs	5.0	6.3	8.9	10.9
12.00-16.00hrs	5.0	6.7	8.9	11.6
16.00-20.00hrs	4.8	5.8	8.6	10.0
20.00-24.00hrs	4.8	5.4	8.6	9.1

Comparison of the above rates with those in Table 4.07 indicates that the air change rates for the integral double glazed space are slightly lower than those for the integral low E glazed space. This is due to the effect of the higher level of insulation, provided by the low E glazing, maintaining higher temperatures in the glazed space. This results in a greater temperature difference between internal and external air resulting in higher air change rates.

The simulation results for internal air temperature and resultant temperature using these air change rates in both models, on Days 201 and 180 are shown in Figures 4.35-4.38.
Figures 4.35 and 4.36, for Day 201, indicate that in the unventilated situation resultant temperature, reached a maximum value of 32.3 °C and the air temperature reached a maximum value of 29.8°C.
Openings of 0.15m^2 reduced these to 27.9°C and 24.2°C respectively and openings of 0.3m^2 reduced these to 26.4°C and 22.2°C respectively.
Without ventilation, during the day and evening, there were 3 hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 9 hours and with openings of 0.3m^2 the resultant temperature remained below 27°C.

Figures 4.37 and 4.38, for Day 180, indicate that in the unventilated situation resultant temperature, reached a maximum value of 44.9 °C and the air temperature reached a maximum value of 41.3°C.
Openings of 0.15m^2 reduced these to 37.3°C and 31.7°C respectively and openings of 0.3m^2 reduced these to 34.9°C and 28.4°C respectively.
Without ventilation, during the day and evening, there were no hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 2 hours and with openings of 0.3m^2 increased this figure to 4 hours.

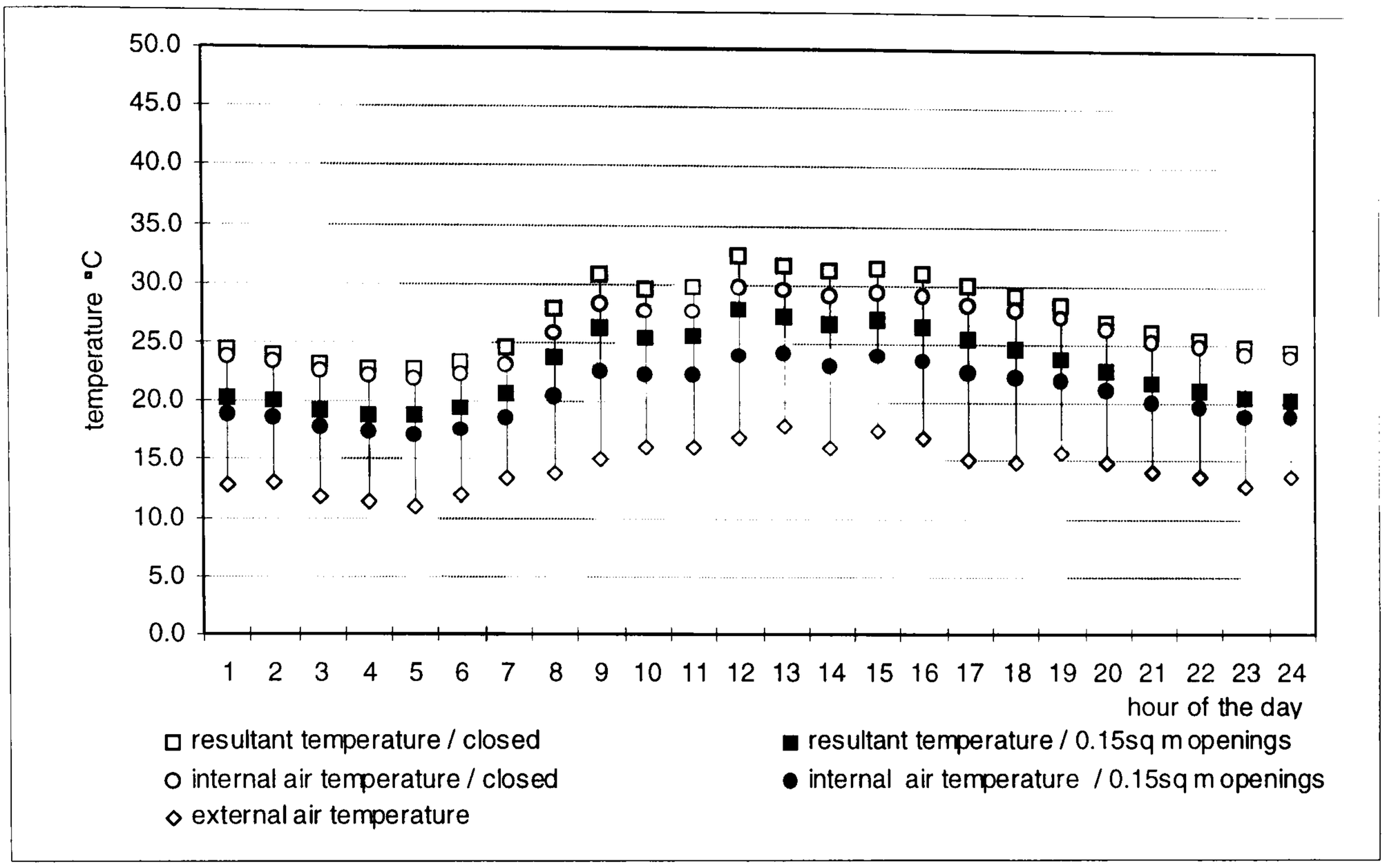


Figure 4.35 **Temperature reduction caused by openings of area 0.15m^2 in the integral, south facing, double glazed space, Day 201**

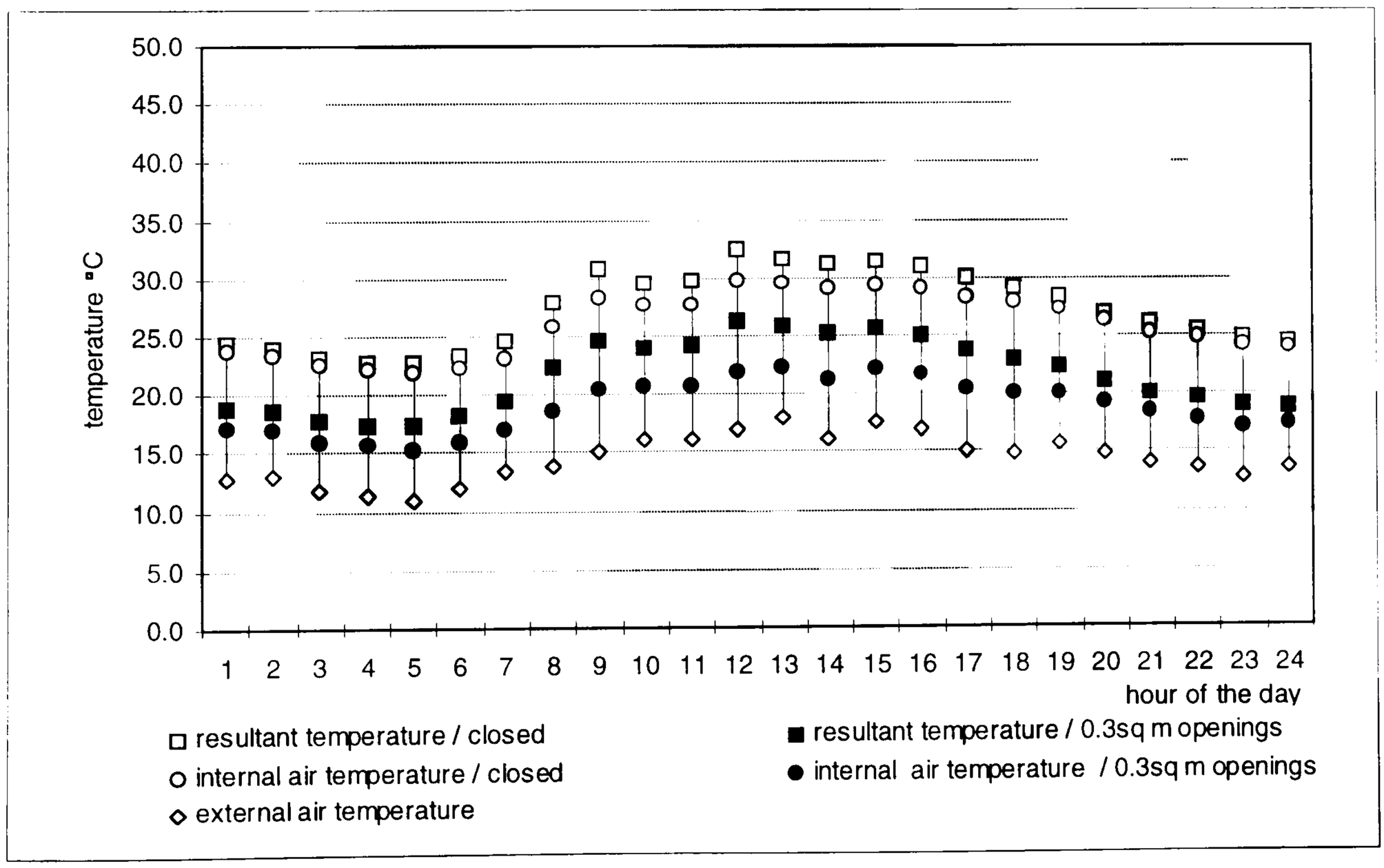


Figure 4.36 **Temperature reduction caused by openings of area 0.3m^2 in the integral, south facing, double glazed space, Day 201**

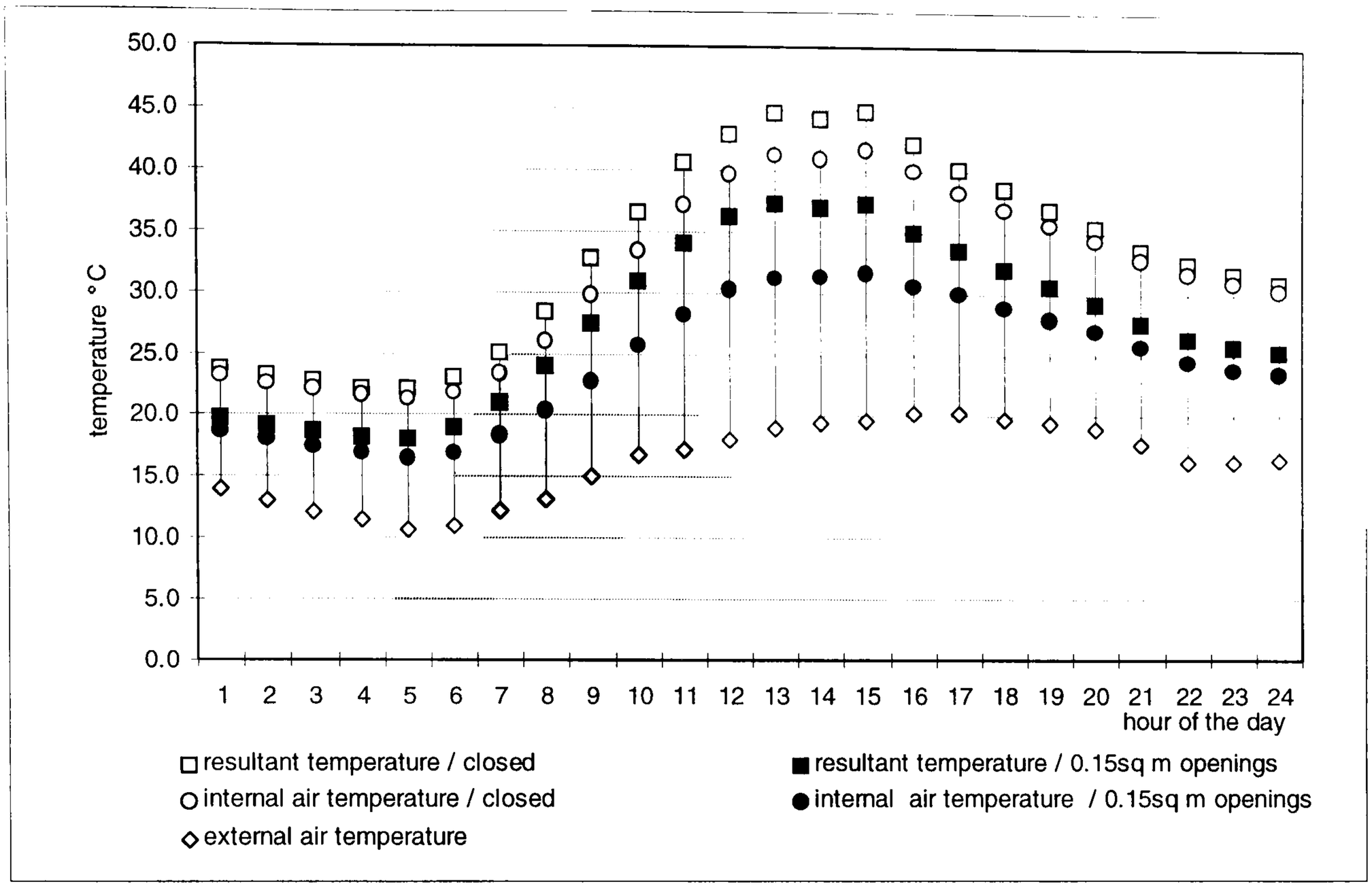


Figure 4.37 **Temperature reduction caused by openings of area 0.15m^2 in the integral, south facing, double glazed space, Day 180**

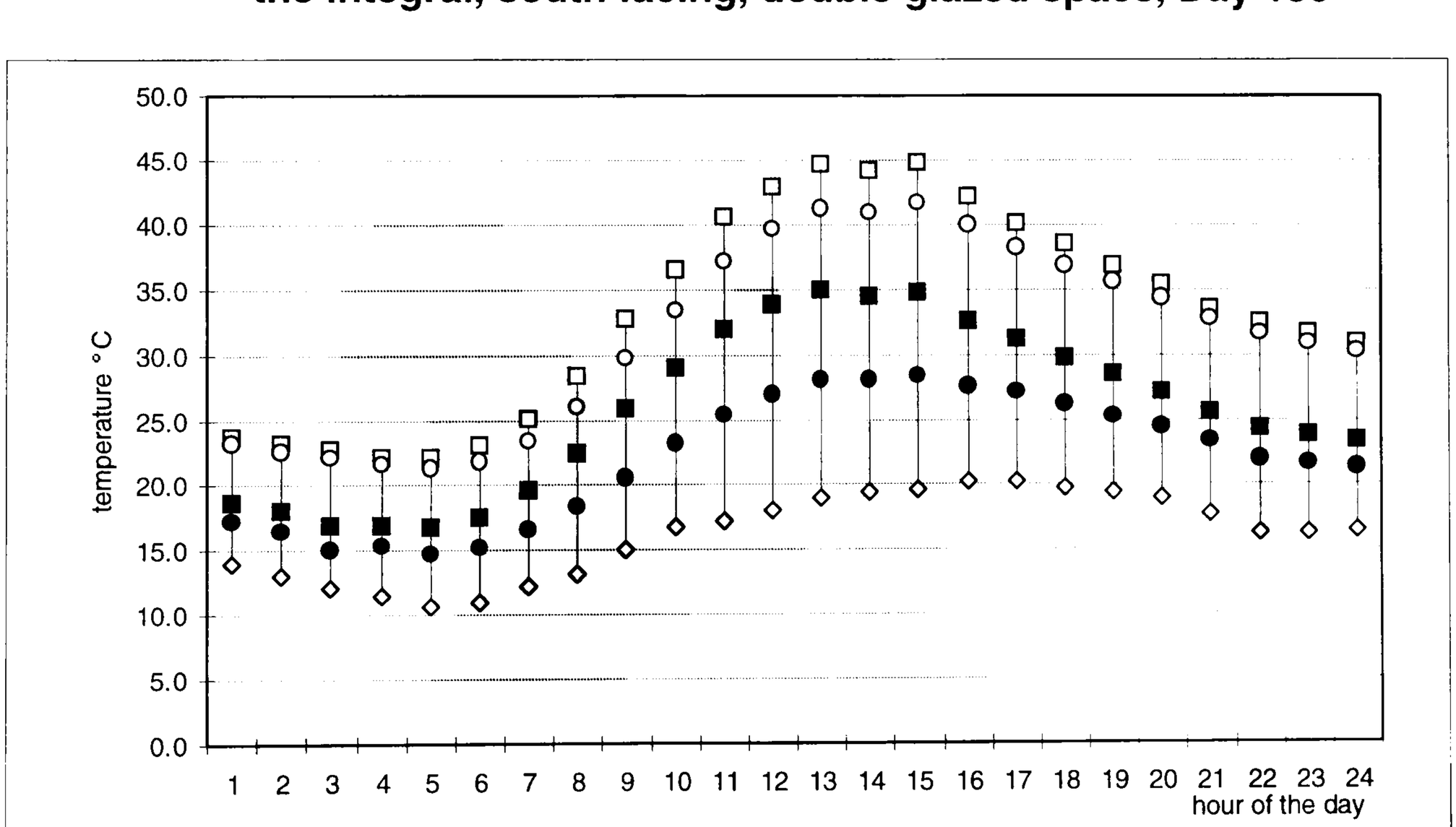


Figure 4.38 **Temperature reduction caused by openings of area 0.3m^2 in the integral, south facing, double glazed space, Day 180**

Estimating the effect of buoyancy driven ventilation during July

Figure 4.35 below illustrates the effect of buoyancy driven ventilation using the Day 201 rates for the month of July. Comparison with the integral low E glazed model [included below] indicates that the number of comfortable hours for the two models with ventilation are very similar although without ventilation the double glazed space had a small number of comfortable hours whereas the low E model had virtually none.

For the 0.3m^2 ventilation openings in the double glazed model, resultant temperatures fell within the comfortable range for 47% of the daytime hours and 70% of the evening hours. As mentioned previously for the low E glazed model the resultant temperatures fell within the comfortable range for 45% of the daytime hours and 68% of the evening hours.

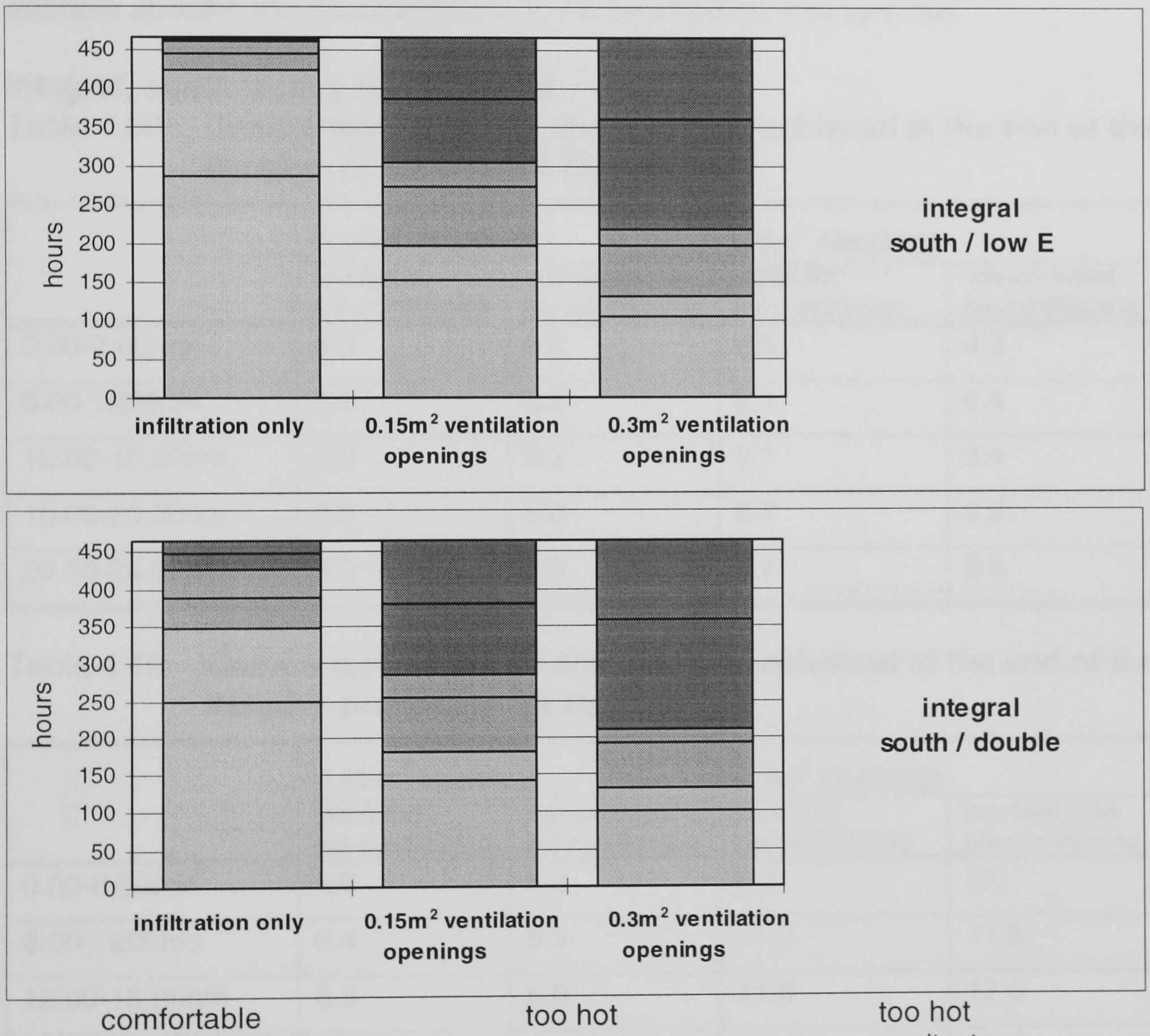


Figure 4.39 **The effect of increasing ventilation rates during July in an integral south facing double glazed space**

Testing the effect of buoyancy driven ventilation for one specific day

The iterative process described, involves changing the air change rates for infiltration air in the internal conditions files for the models under test. Since the simulation process includes several days of pre-conditioning before the test day, the air change rates inserted will also be used for the this pre-conditioning period, implying that ventilators will have been open for several days before the test day. In practice it is probable that ventilators will be used continuously for the summer period and so this method of incorporating the air change rates into the model was adopted for the ventilation studies. However a small study was undertaken on the south facing, integral, low E glazed model to test the effect of opening the ventilators only for the test day. This was achieved by identifying the test day separately on the calendar for the model, which then enables specific internal conditions to be inserted for that one day.

Integral, south facing, low E glazed

Table 4.09 **Comparison of the air change rates achieved at the end of the iterative processes for Day 201**

	0.15m^2 openings		0.3m^2 openings	
	ventilated pre-conditioning	non-ventilated pre-conditioning	ventilated pre-conditioning	non-ventilated pre-conditioning
0.00-8.00hrs	4.9	5.2	8.5	9.3
8.00-1200hrs	5.2	5.3	9.1	9.4
12.00-16.00hrs	5.2	5.3	9.1	9.4
16.00-20.00hrs	5.0	5.0	8.7	8.8
20.00-24.00hrs	5.0	5.0	8.7	8.8

Table 4.10 **Comparison of the air change rates achieved at the end of the iterative processes for Day 180**

	0.15m^2 openings		0.3m^2 openings	
	ventilated pre-conditioning	non-ventilated pre-conditioning	ventilated pre-conditioning	non-ventilated pre-conditioning
0.00-8.00hrs	4.8	5.2	8.3	9.0
8.00-1200hrs	6.4	6.5	11.3	11.5
12.00-16.00hrs	6.3	6.8	11.0	12.0
16.00-20.00hrs	5.5	6.0	9.5	10.5
20.00-24.00hrs	5.5	5.6	9.5	9.5

As can be expected the models which did not have any ventilation during the pre-conditioning period produced higher air change rates, particularly from midnight-8.00hrs, than those with ventilated pre-conditioning. In the latter case the ventilation during the pre-conditioning period had the effect of reducing the

quantity of heat stored in the dividing walls and the floor and thus reducing the mean radiant, air, and resultant temperatures within the space. The temperature difference between internal and external air was also therefore reduced, thus lowering the resulting air change rates. The effect of the ventilated pre-conditioning period in reducing temperatures can be seen in Table 4.11 below.

Table 4.11 **Simulation results for Day 180 with 0.3m^2 ventilation openings in the integral, south facing, double glazed space, with and without ventilated pre-conditioning**

	ventilated pre-conditioning			non-ventilated pre-conditioning		
	air temperature °C	mean radiant temperature °C	resultant temperature °C	air temperature °C	mean radiant temperature °C	resultant temperature °C
1	17.2	20.0	18.6	18.8	23.5	21.2
2	16.5	19.5	18.0	18.3	22.6	20.5
3	15.8	18.9	17.4	17.4	21.8	19.6
4	15.3	18.4	16.9	16.8	21.1	19.0
5	14.8	18.6	16.7	16.2	21.1	18.6
6	15.2	20.0	17.6	16.5	22.4	19.4
7	16.6	22.6	19.6	17.8	24.8	21.3
8	18.4	26.5	22.5	19.5	28.5	24.0
9	20.6	31.0	25.8	21.6	32.8	27.2
10	23.2	34.7	29.0	24.1	36.4	30.3
11	25.4	38.6	32.0	26.2	40.2	33.2
12	27.0	40.6	33.8	27.8	42.0	34.9
13	28.0	41.8	34.9	28.8	43.2	36.0
14	28.1	40.9	34.5	28.8	42.2	35.5
15	28.4	41.3	34.8	29.0	42.5	35.8
16	27.6	37.6	32.6	28.2	38.8	33.5
17	27.1	35.3	31.2	27.7	36.5	32.1
18	26.2	33.4	29.8	26.7	34.5	30.6
19	25.3	31.6	28.5	25.9	32.6	29.3
20	24.5	29.8	27.1	25.0	30.8	27.9
21	23.3	27.8	25.6	23.9	28.8	26.3
22	22.0	26.7	24.4	22.5	27.7	25.1
23	21.6	26.0	23.8	22.1	26.9	24.5
24	21.3	25.4	23.3	21.8	26.3	24.0

Exposed and Integral, North Facing, Low E Glazed Models

The third set of models to be used for the investigation of buoyancy driven ventilation were the north facing, exposed and integral, low E glazed spaces. The procedure used for the south facing versions, with ventilated pre-conditioning, was repeated for the north facing models and the results are presented below

Exposed, north facing, low E glazed space

Table 4.12 **The air change rates achieved at the end of the iterative process for Day 201 and Day 180**

	0.15m^2 openings		0.3m^2 openings	
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h
0.00-8.00hrs	4.5	4.6	7.7	7.2
8.00-1200hrs	5.4	6.3	9.3	11.3
12.00-16.00hrs	5.4	6.6	9.3	11.4
16.00-20.00hrs	4.6	5.1	7.7	8.9
20.00-24.00hrs	4.6	4.0	7.7	7.0

Integral, north facing, low E glazed space

Table 4.13 **The air change rates achieved at the end of the iterative process for Day 201, Day 180 and Day 184**

	0.15m^2 openings		0.3m^2 openings	
	Day 201 ac/h	Day 180 ac/h	Day 201 ac/h	Day 180 ac/h
0.00-8.00hrs	4.9	4.7	8.6	8.3
8.00-1200hrs	5.0	5.3	8.6	9.6
12.00-16.00hrs	5.0	5.5	8.6	9.5
16.00-20.00hrs	5.0	5.0	8.7	8.7
20.00-24.00hrs	5.0	4.8	8.7	8.3

Comparison of the above air change rates with those for the similar south facing models, Tables 4.06 and 4.07 show that for Day 201 a day with very low levels of direct solar radiation the air change rates for the integral models are very close, due to the similar exposure to diffuse solar radiation. The Day 201 figures for the exposed situation are also close in the evening and overnight.

For Day 180 the air change rates predicted for the north facing models are lower than those for the south facing models due to the shading of the glazed space by the house, resulting in lower internal temperatures and hence lower air change rates.

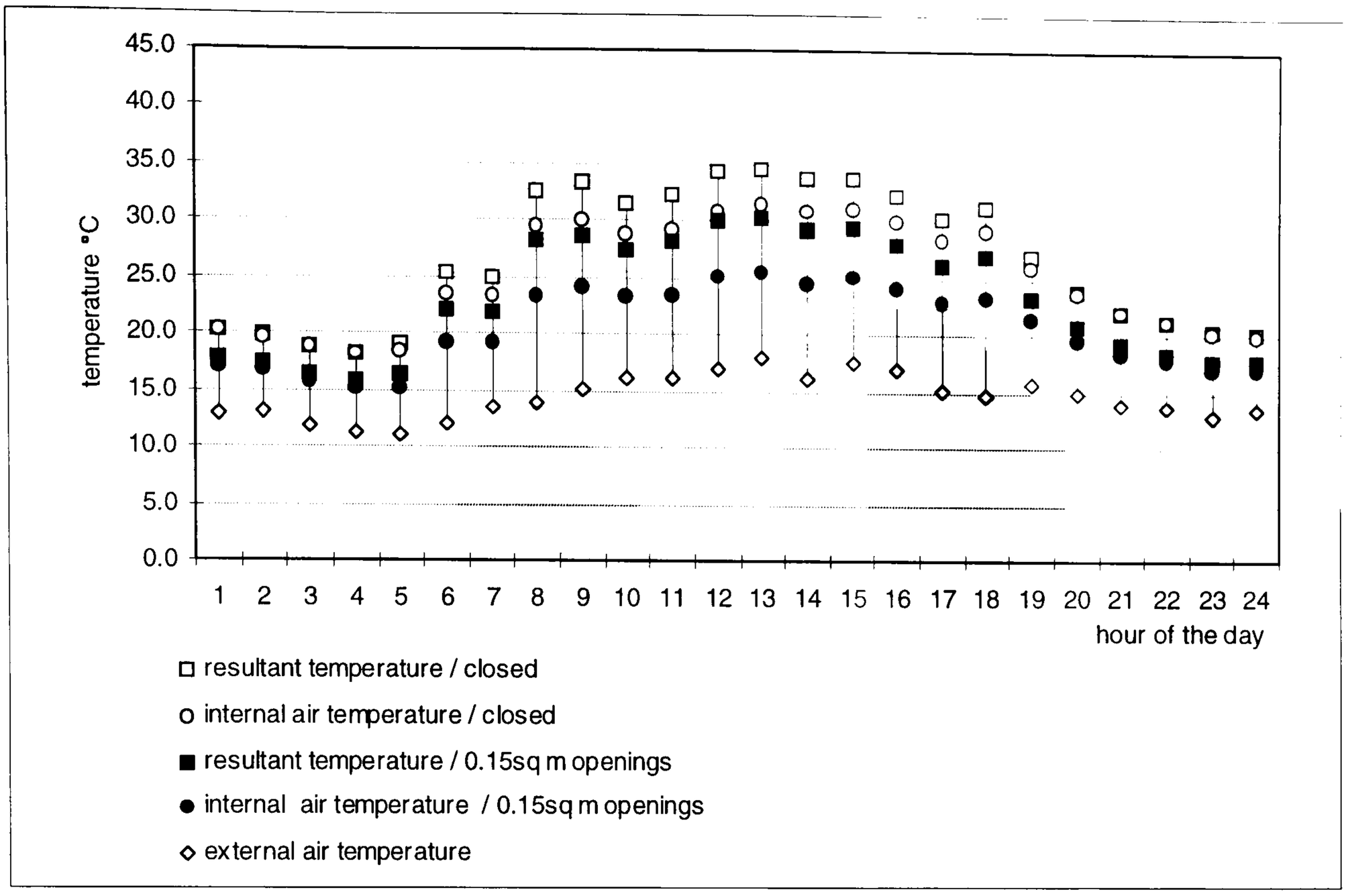


Figure 4.40 **Temperature reduction caused by openings of area 0.15m^2 in the exposed, north facing, low E, glazed space, Day 201**

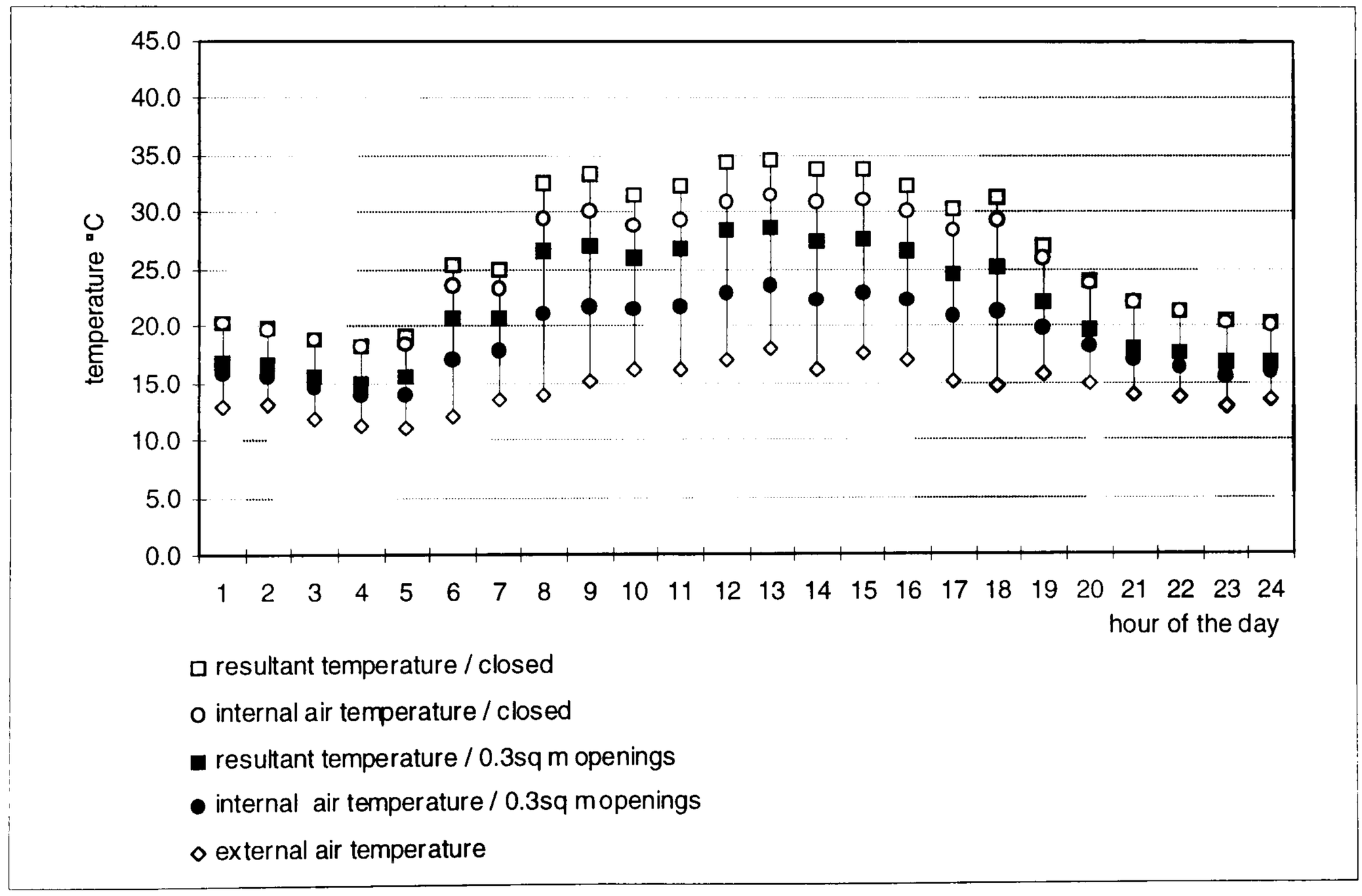


Figure 4.41 **Temperature reduction caused by openings of area 0.3m^2 in the exposed, north facing, low E glazed space, Day 201**

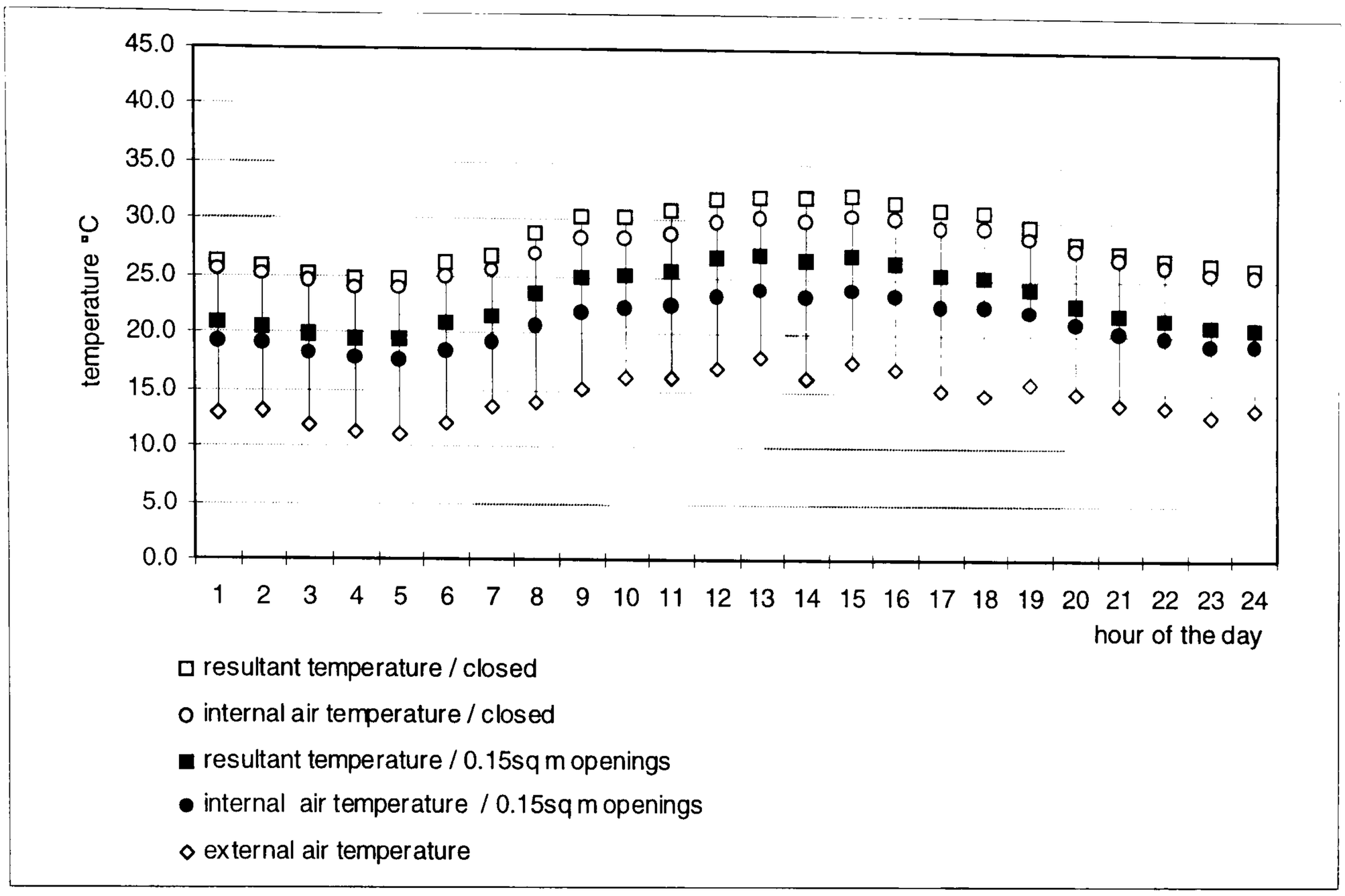


Figure 4.42 **Temperature reduction caused by openings of area 0.15m^2 in the integral, north facing, low E glazed space, Day 201**

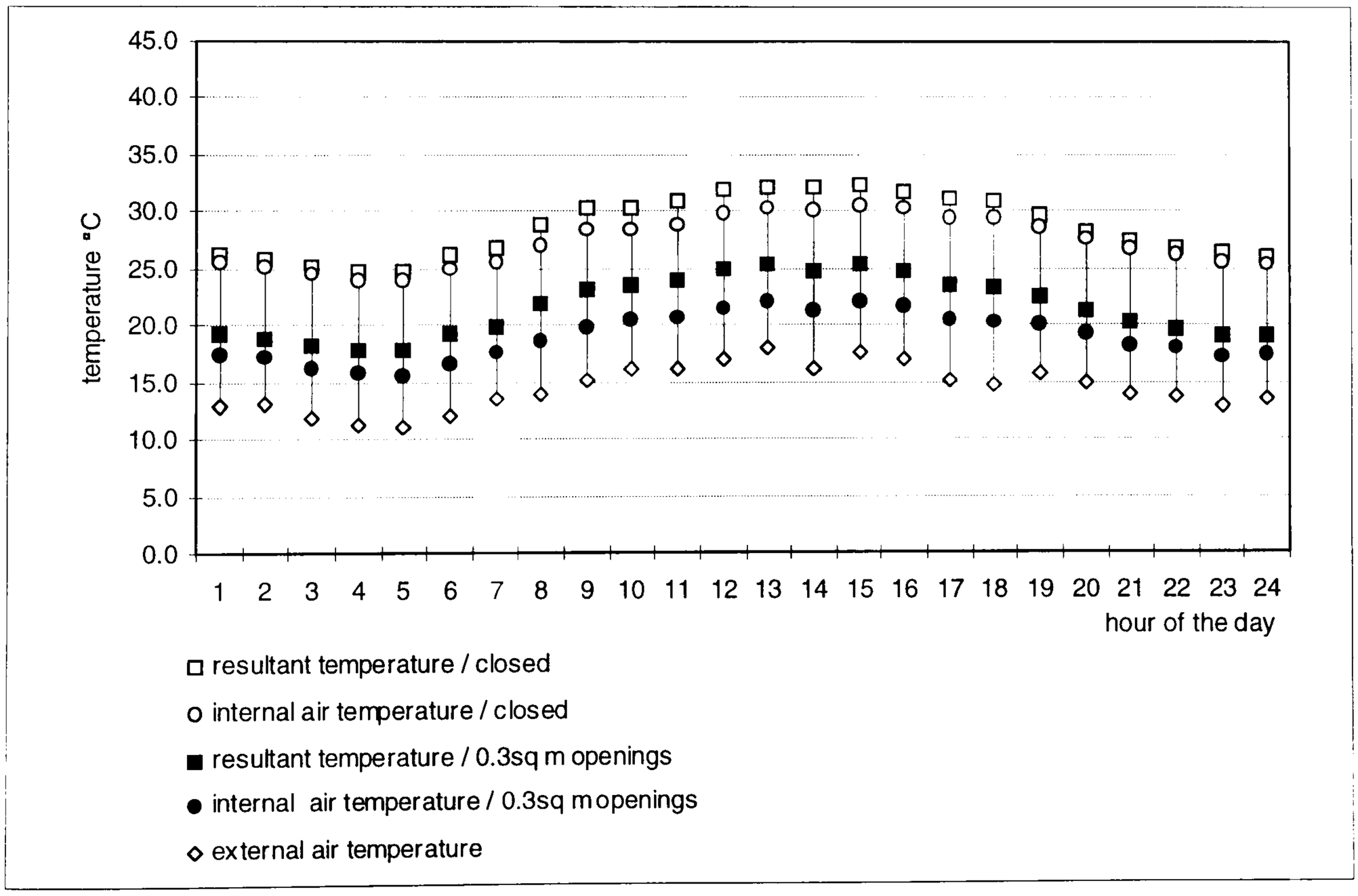


Figure 4.43 **Temperature reduction caused by openings of area 0.3m^2 in the integral, north facing, low E glazed space, Day 201**

Analysis of the results for Day 201

Exposed, north facing, lowE glazed space

Figures 4.36 and 4.37 indicate that the initial resultant temperature, without ventilation, reached a maximum value of 34.6°C and the initial air temperature reached a maximum value of 31.4°C.
Openings of 0.15m^2 reduced these to 30.3°C and 25.6°C respectively.
Openings of 0.3m^2 reduced them to 28.6°C and 23.5°C respectively.
Without ventilation, during the day and evening there were 5 hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 7 hours and openings of 0.3m^2 increased this figure to 10 hours.

Integral north facing, low E glazed space

Figures 4.38 and 4.39 indicate that the initial resultant temperature, without ventilation, reached a maximum value of 32.2°C and the initial air temperature reached a maximum value of 30.4°C.
Openings of 0.15m^2 reduced these to 27.0°C and 24.0°C respectively and openings of 0.3m^2 reduced them to 25.4°C and 22.1°C respectively.
Without ventilation, during the day and evening there were 2 hours when the resultant temperature fell below 27°C. Openings of both 0.15m^2 and 0.3m^2 brought the resultant temperature down below 27°C for the whole 24 hour period.

Comparison of the results for the integral and exposed glazed spaces

The results for the north facing glazed spaces for Day 201, illustrate again the effect of the increased thermal storage and reduced glazing area, provided by the integral space in producing longer, thermally comfortable periods than the exposed space.

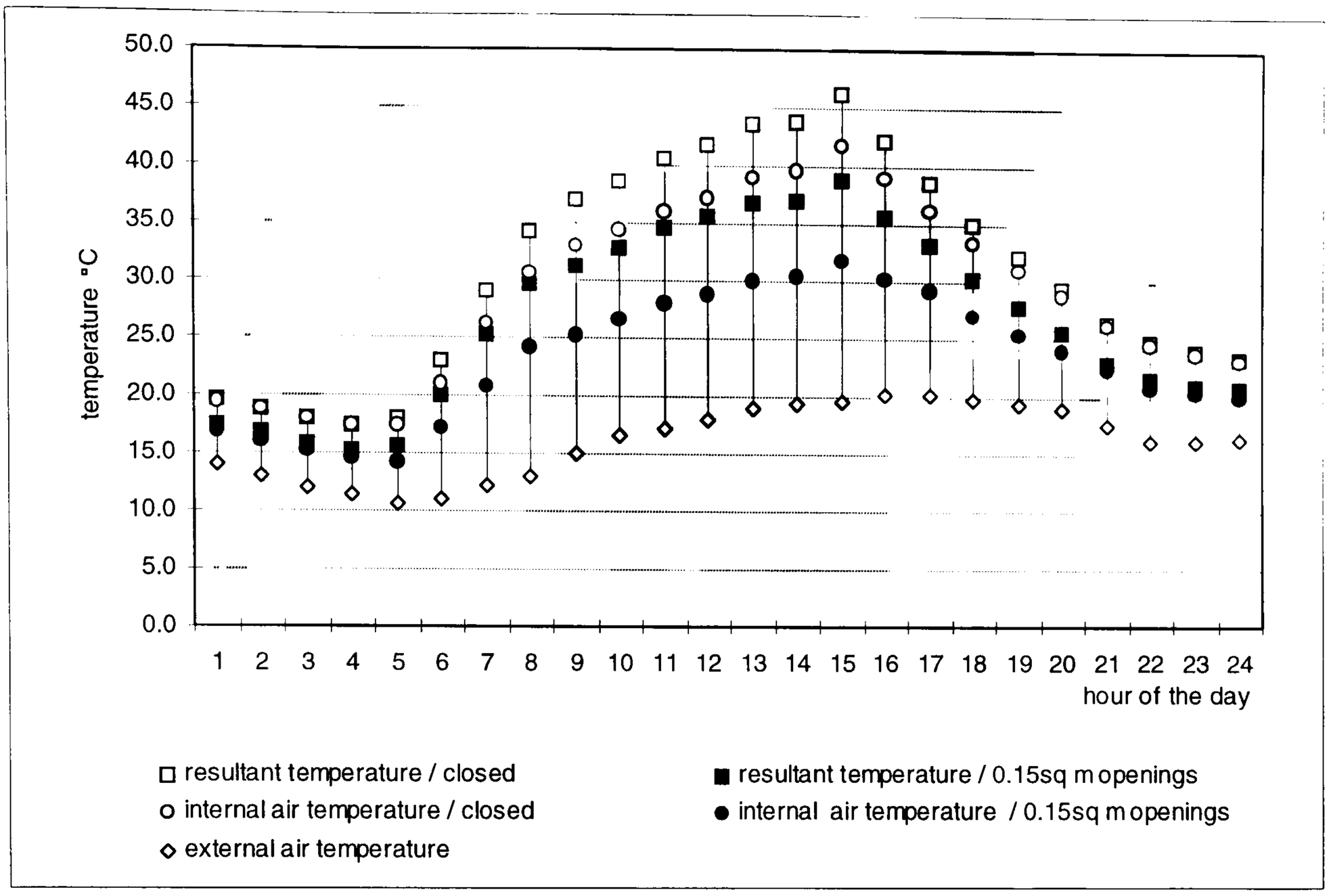


Figure 4.44 **Temperature reduction caused by openings of area 0.15m^2 in the exposed, north facing, low E glazed space, Day 180**

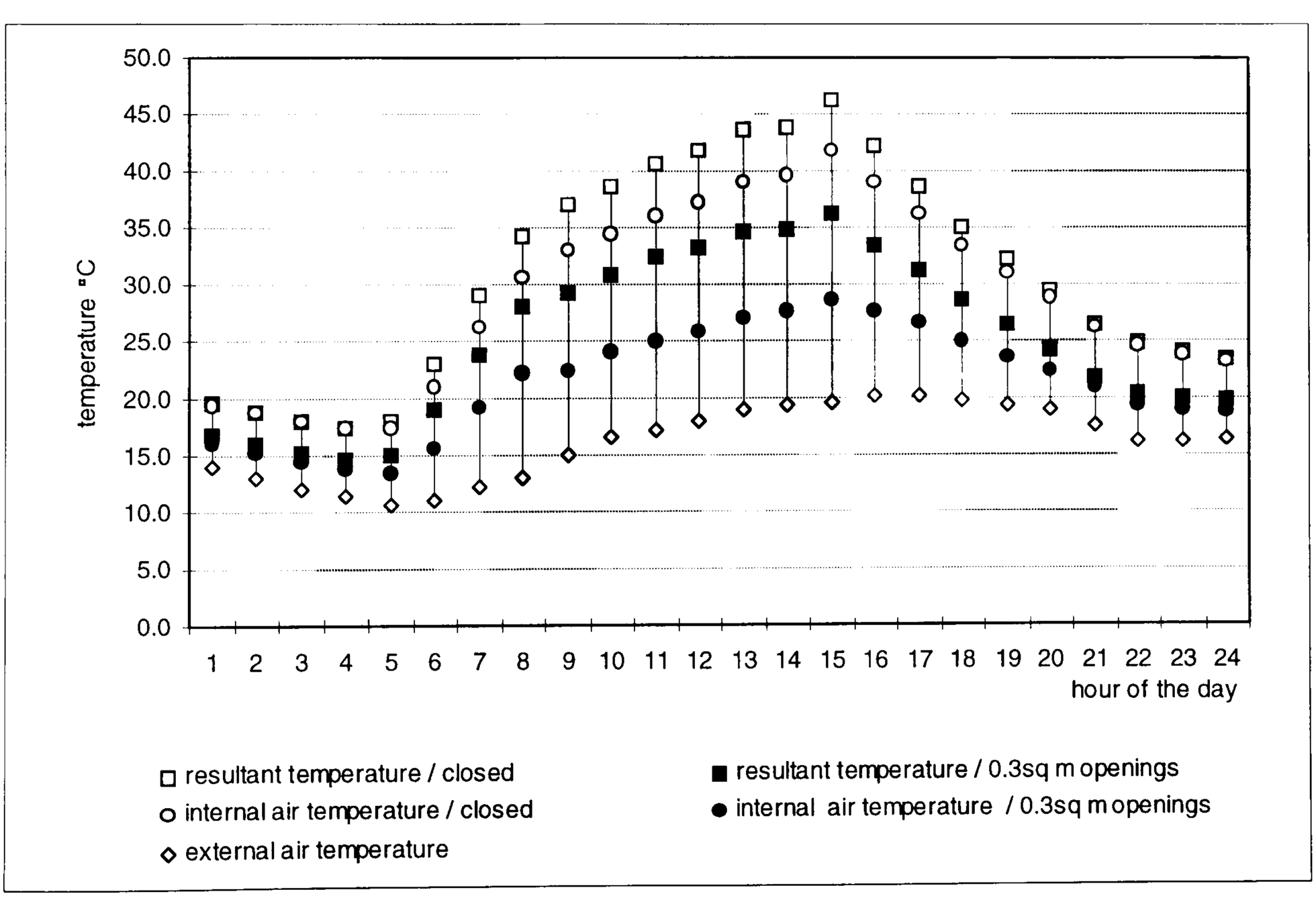


Figure 4.45 **Temperature reduction caused by openings of area 0.3m^2 in the exposed, north facing, low E glazed space, Day 180**

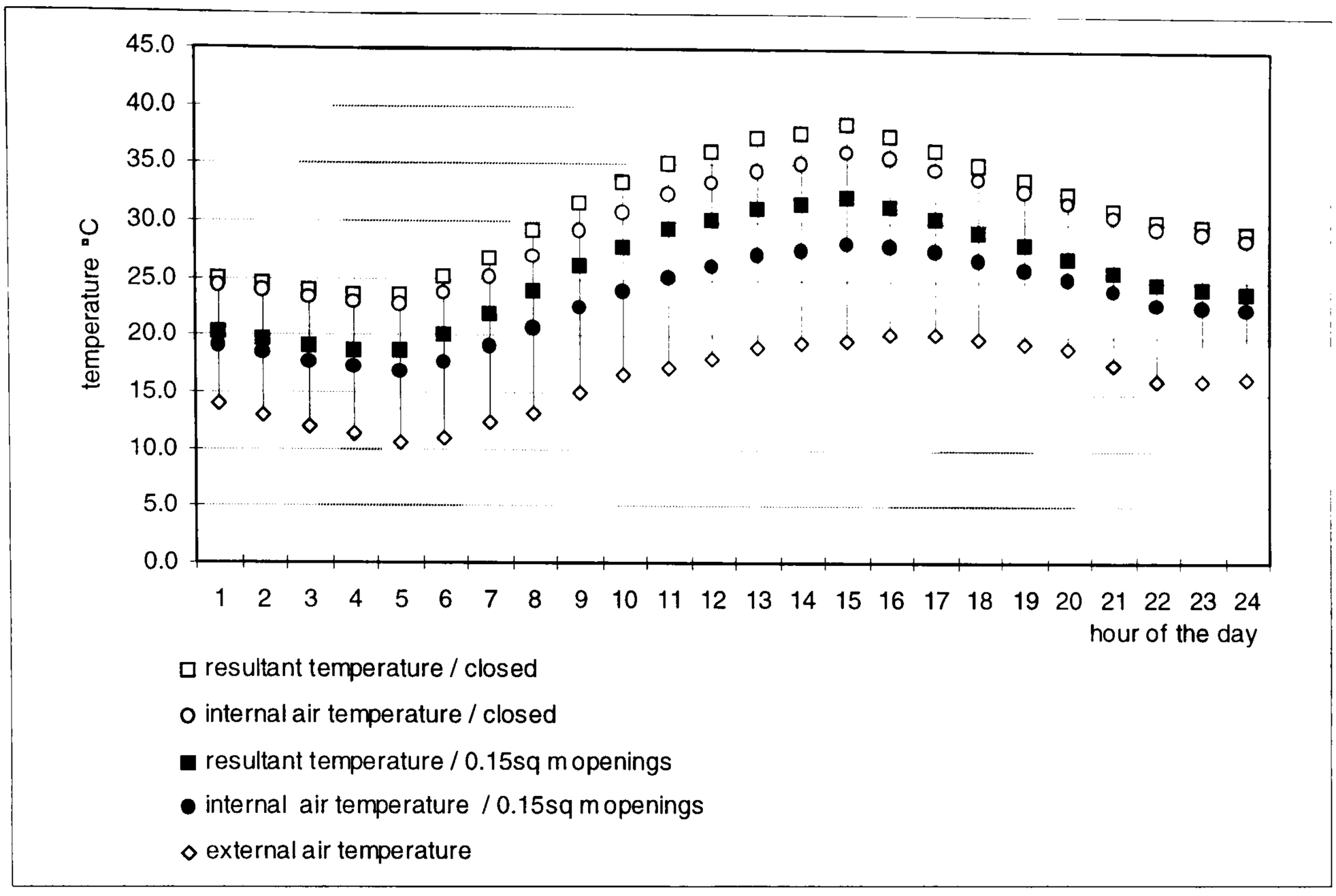


Figure 4.46 **Temperature reduction caused by openings of area 0.15m^2 in the integral, north facing, low E glazed space, Day 180**

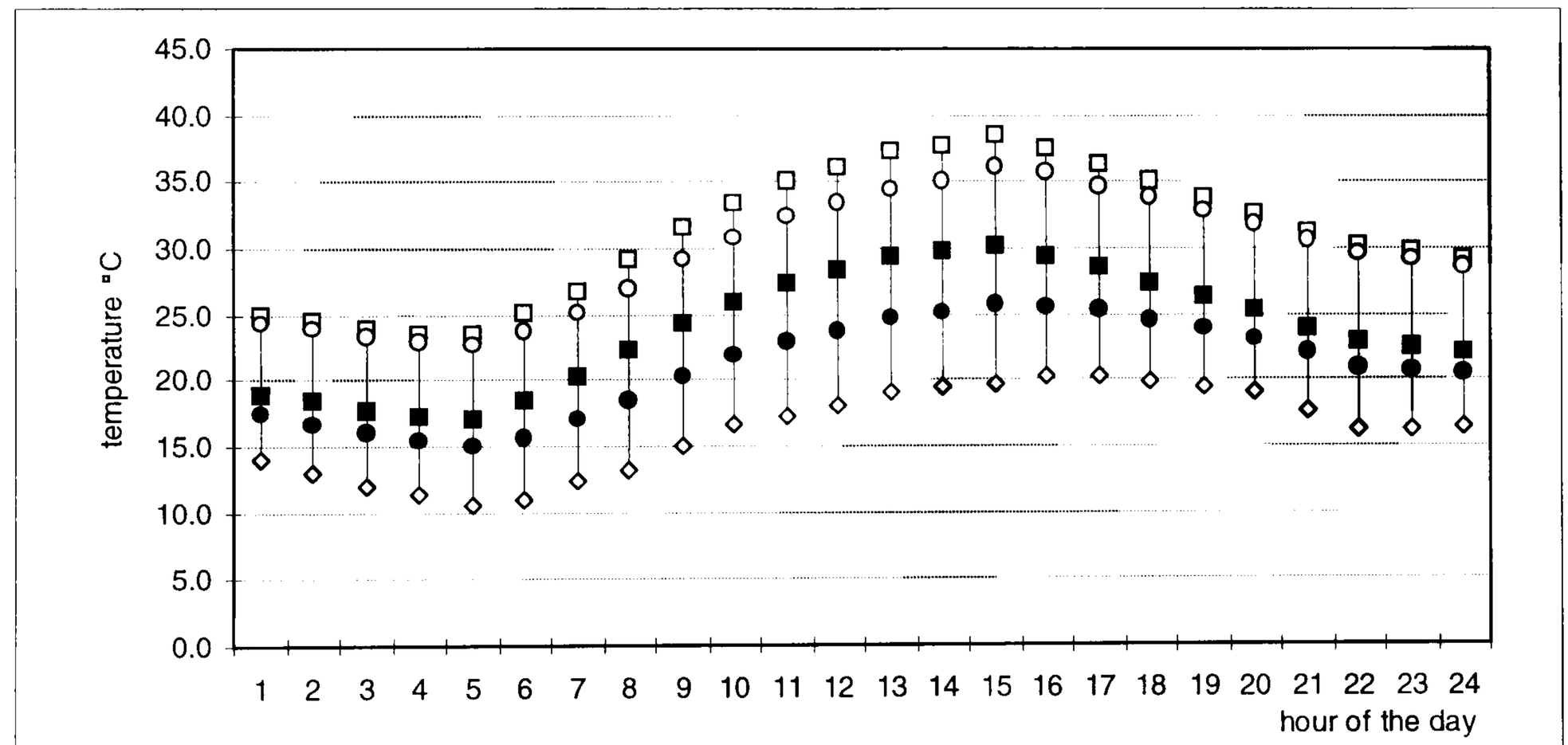


Figure 4.47 **Temperature reduction caused by openings of area 0.3m^2 in the integral, north facing, low E glazed space, Day 180**

Analysis of the results for Day 180

Exposed, north facing, lowE glazed space

Figures 4.40 and 4.41 indicate that the initial resultant temperature, without ventilation, reached a maximum value of 46.1°C and the initial air temperature reached a maximum value of 41.8°C.
Openings of 0.15m^2 reduced these to 38.8°C and 31.9°C respectively.
Openings of 0.3m^2 reduced them to 36.3°C and 28.7°C respectively.
Without ventilation, during the day and evening there were 3 hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 4 hours and openings of 0.3m^2 increased this figure to 5 hours.

Integral north facing, low E glazed space

Figures 4.42 and 4.43 indicate that the initial resultant temperature, without ventilation, reached a maximum value of 38.6°C and the initial air temperature reached a maximum value of 36.1°C.
Openings of 0.15m^2 reduced these to 32.3°C and 28.2°C respectively and openings of 0.3m^2 reduced them to 30.3°C and 25.7°C respectively.
Without ventilation, during the day and evening there were no hours when the resultant temperature fell below 27°C. Openings of 0.15m^2 increased this figure to 5 hours and openings of 0.3m^2 increased this figure to 8 hours.

Estimating the effect of boyancy driven ventilation during July

Figure 4.44 below illustrates the effect of buoyancy driven ventilation using the air change rates achieved on Day 201, for each model, for the whole of the month of July.

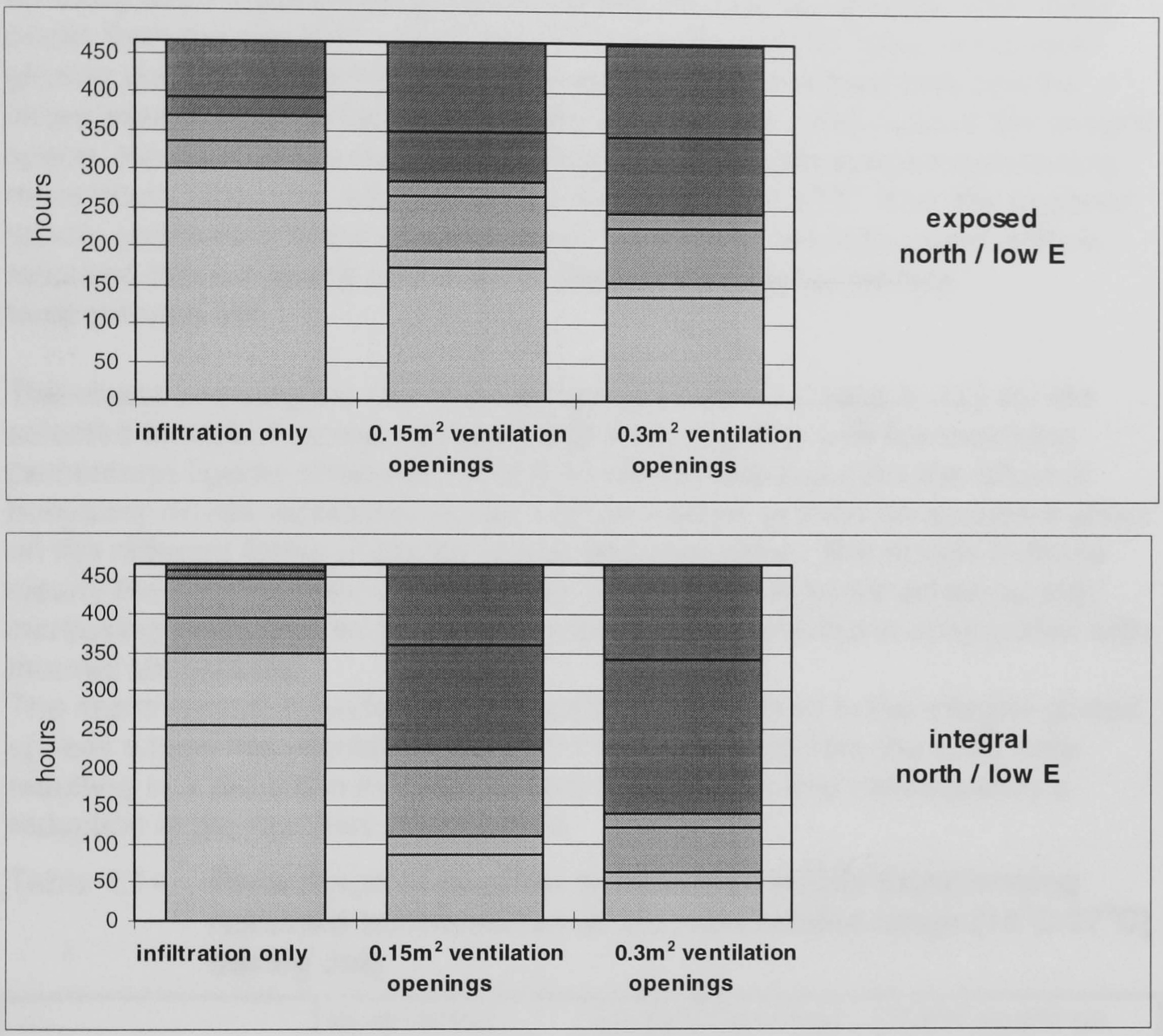


Figure 4.48 **The effect of increasing ventilation rates during July in the exposed and integral north facing lowE glazed spaces**

The above charts indicate that for the exposed glazed space with $0.3m^2$ ventilation openings, the resultant temperature fell within the comfortable range for 33% of the daytime hours and 76% of the evening hours.
For the integral glazed space with $0.3m^2$ ventilation openings, the resultant temperature fell within the comfortable range for 65% of the daytime hours and 80% of the evening hours.

Conclusions on the ventilation study

The one day simulations indicate clearly the different profiles of resultant temperatures occurring in the unventilated exposed and integral glazed spaces . The exposed situation is characterised by rapid response to incident solar radiation with high peaks and troughs. The integral spaces experience a far more even resultant temperature profile with warmer troughs and cooler peaks than the exposed space. This is due to the smaller area of external glazing leading to less incident solar radiation and less heat loss and the larger area of thermal storage provided by the three solid walls of the integral space. However these factors also result in the integral space experiencing more hours when the resultant temperature is above 27°C than the exposed space, particularly in the evening when the stored heat in the solid walls is released into the space as the air temperature and other surface temperatures fall.

The charts showing the effect of increasing ventilation rates in July for the selected models, Figures 4.34,4.35 and 4.44, together with the matching percentage figures shown in Table 4.14 below, illustrate both the effect of buoyancy driven ventilation on each of the models and the comparative effect on the different forms of glazed space and orientation. The results indicate clearly the improvement in the number of comfortable hours achieved with increasing ventilation as predicted by the iterative process in conjunction with thermal simulations

The improvement in performance is particularly marked in the integral glazed spaces where the ventilation cools and removes heat from the solid walls resulting in a reduction in mean radiant temperature and consequently a reduction in the resultant temperature.

Table 4.14 **Percentage of daytime or evening periods experiencing resultant temperatures in the comfortable range [16°C-27°C] during July**

	unventilated - infiltration only		0.15m^2 openings high and low level		0.3m^2 openings high and low level	
	daytime	evening	daytime	evening	daytime	evening
north exposed low E	8%	46%	21%	74%	33%	76%
north integral low E	3%	6%	44%	68%	65%	80%
south exposed low E	7%	37%	22%	65%	28%	74%
south integral low E	1%	2%	26%	51%	45%	68%
south integral double	6%	11%	31%	55%	47%	70%

During July the maximum ambient air temperature reached in the south-east weatherfile was 25.8°C

4. 05 Investigation of the Effect of Increasing the Thermal Storage Properties of the Floor Construction of the Glazed Space

Sources used in the background research to this project, [Chapter 1.05] suggested that the thermal mass of the floor of a conservatory could be used in order to control high temperatures occurring in glazed spaces. A further study was therefore undertaken to investigate this effect.
The north and south facing, integral and external, double glazed models were chosen for this study in order to provide a suitable range of conditions.
The original glazed space models had concrete slab floors finished with a thin carpet layer on screed as described and discussed in the Chapter 2.08 on building constructions. A second floor construction was therefore devised using a 10mm clay tile in a screed bed on a concrete slab.
The U values of the two floor constructions were very close; with carpet finish, 0.299 W/m^{2}K; with clay tile finish 0.291 W/m^{2}K.
Table 4.15 below lists the relevant properties of the two floor finishing materials and compares their heat storage capacities.

Table 4.15 **Comparison of the heat storage capacities of a carpet layer and a clay tile layer**

	density kg/m^3	specific heat capacity J/kg K	thermal capacity kJ/ m^3 K	thickness of layer m	thermal capacity of layer kJ/ m^2 K
carpet	186	1360	252.96	0.005	1.265
clay tile	1,900	837	1,590.30	0.010	15.903

The clay tile floor construction was substituted into the chosen models in place of the original construction. The thermal simulation process was repeated for the year and results for the comfortable hours in the glazed spaces, based on predicted resultant temperatures, obtained as before.
In theory the clay tiled floor should have been able to absorb and store solar gain during the daytime and release the heat in the evening, as the temperature in the glazed space fell. Thus thermal comfort should have been improved, during the daytime due to the storage of excessive solar gain, and during the evening by the release of the stored heat.
The effects were measured over the usable hours of the year from 8.00-23.00hrs [15 hours per day] a total of 5,475 hours per year.

An assessment of the simulation results in comparison with the original results using a carpeted finish is presented in Table 4.16 and discussed overleaf.

The effect on the number of comfortable hours, occurring in the glazed spaces, due to the additional thermal storage provided by the clay tiled floor construction

The integral, south facing, double glazed model
A slight increase in the comfortable hours in the mornings [October-May] and in the afternoons [February-March, October-December] due to cooling effect of the additional thermal storage.
A slight decrease in the comfortable hours in the evenings [May-August] due to the release of stored heat keeping the resultant temperature above 27°C.

The exposed, south facing, double glazed model
A slight increase in comfortable hours in the mornings [January-September] and afternoons [April-June, October-November] due to the cooling effect of the thermal storage.
A slight increase in comfortable hours in the evenings [April and October] due to the release of stored heat.
A slight decrease in comfortable hours in the evenings [June-September] due to the release of stored heat.

The integral, north facing, double glazed model
A slight increase in the comfortable hours in the mornings [May and August] due to the cooling effect.
A slight decrease in comfortable hours in the mornings [March-April, October-November] due to the release of stored heat.
A slight increase in comfortable hours in the afternoons [April-May, August-September] due to the cooling effect.
A slight decrease in the comfortable hours in the evenings [May-July] due to the release of stored heat.

The exposed, north facing, double glazed model
A slight increase in the comfortable hours in the mornings [May - August] due to the cooling effect.
A slight decrease in the comfortable hours in the mornings [March-April, October-November] due to the excessive cooling effect of the thermal storage.
A slight increase in the comfortable hours in the afternoons [May - August] due to the cooling effect.
A slight decrease in the comfortable hours in the afternoons [March, October-November] due to the excessive cooling effect of the thermal storage.
A slight increase in the comfortable hours in the evenings [May-June, September] due to the release of stored heat.
A slight decrease in the comfortable hours in the evenings [June-July] due to the release of stored heat.

The effects of the additional thermal storage capacity provided by the clay tiled floor construction are complex and often conflicting. The storage and

release of heat can have both positive and negative effects, depending on the time of day and year. However as the table below shows, the number of hours involved in any of these effects is negligible.

Table 4.16 **The changes in the number of comfortable hours due to the effect of the clay tiled floor construction**

Integral, south facing, double glazed

effect	number of hours	months	time of day	cause
increase	24	Oct-May	mornings	reduction in hours > 27°C
increase	6	Feb-March Oct-Dec	afternoons	reduction in hours > 27°C
decrease	10	May-August	evenings	increase in hours > 27°C

Exposed, south facing, double glazed

effect	number of hours	months	time of day	cause
increase	26	Jan-Sept [not March]	mornings	reduction in hours > 27°C
increase	12	Apr-Jun	afternoons	reduction in hours > 27°C
increase	15	Oct-Nov	evenings	increase in hours > 16°C
decrease	27	Jun-Sept	evenings	increase in hours > 27°C

Integral, north facing, double glazed

effect	number of hours	months	time of day	cause
increase	4	May and Aug	mornings	reduction in hours > 27°C
decrease	13	Mar-Apr Oct-Nov	mornings	reduction in hours > 27°C
increase	12	Apr-May Aug-Sept	afternoons	reduction in hours > 27°C
decrease	5	May-July	evenings	increase in hours > 27°C

Exposed, north facing, double glazed

effect	number of hours	months	time of day	cause
increase	23	May and Aug	mornings	reduction in hours > 27°C
decrease	15	Mar-Apr Oct-Nov	mornings	reduction in hours > 16°C
increase	21	Apr-Sept	afternoons	reduction in hours > 27°C
decrease	9	March and Oct-Nov	afternoons	reduction in hours > 16°C
increase	10	May-June September	evenings	increase in hours > 16°C
decrease	8	June-July	evenings	increase in hours > 27°C

4. 06 Investigation of the Effect of Internal and External Shading Blinds Together with Ventilation on Thermal Comfort in the Glazed Space

Earlier studies on the use of highly glazed spaces such as domestic conservatories, have included the use of shading blinds in order to overcome the problems of overheating. The use of blinds has also been recommended as a measure to overcome glare. [Chapter 1.05].
A limited study was therefore undertaken within this thesis to investigate, by thermal simulation, the effect of both internal and external roof shading blinds, on the temperatures in the integral, south facing, double glazed space.
The one day simulations performed for the ventilation studies indicated that the temperatures in the integral models peaked at much lower levels than those in the exposed design due to the reduced area of glazing and by the heat storage properties of the masonry dividing walls. This suggested that a roof blind would have more effect in controlling temperatures in the integral space, with only one glazed wall in addition to the shaded roof, than in the exposed space with three glazed walls.
The Tas program provides the facility for simulating the closing and opening of blinds or shutters at times of the day specified by the operator. The period chosen for this study, when the blinds should be closed, was from 8.00hrs until 17.00hrs GMT [9.00 -18.00hrs BST].
Building constructions were created for the double glazing with a medium internal blind and for double glazing with an external medium blind.
[See Appendix E]
The individual blind constructions were entered into separate copies of the building model with the integral, south facing, double glazed space. Each model was set up so that during the course of the thermal simulation the double glazed roof construction would be replaced by the double glazed roof construction with internal or external blind, during the appropriate period. The blinds were, by default, included in the thermal simulations for the pre-conditioning days prior to the day under test.
Day 180 was chosen from the weatherfile for the simulation, as it was a day of bright sunlight when a blind would be needed to control glare.
In a further set of simulations the iterative procedure for buoyancy driven ventilation was also used in conjunction with each of the blinds in order to assess the effect of the combination of the blinds and ventilation. The air change rates were inserted into the internal conditions files for the models and were therefore also used during the pre-conditioning period of the thermal simulation.
The air change rates achieved at the end of the iterative process for Day 180 for each model are included overleaf in Table 4.17

Table 4.17 **The air change rates achieved at the end of the iterative process for Day 180**

	internal blind + 0.3m^2 openings	external blind + 0.3m^2 openings	ventilation only 0.3m^2 openings
	ac/h	ac/h	ac/h
0.00-8.00hrs	7.7*	7.5*	8.3
8.00-12.00hrs	11.7	8.3	11.3
12.00-16.00hrs	11.7	8.0	11.0
16.00-20.00hrs	8.9	7.3	9.5
20.00-24.00hrs	8.4	7.3	9.5

* the air change rates are different for the first eight hours when the blinds are not in place due to the effect on radiant temperatures, of the blinds being in operation for the pre-conditioning period.

The results of the one day simulations in terms of the resultant temperatures predicted for the glazed space with blinds alone and with blinds plus ventilation are presented overleaf in Figures 4.49 and 4.50. The resultant temperatures for the glazed spaces with ventilation alone and without blinds or ventilation are also included in the charts for comparison.

Analysis of the results of the one day simulations

The resultant temperatures in Figure 4.49 predict that the internal roof blind alone slightly increases the resultant temperature during the morning period but reduces the resultant temperature by 2-3°C during the afternoon period. In conjunction with ventilation the internal blind appears to improve the performance of the ventilation strategy by again reducing the resultant temperature by approximately 2°C.

In Figure 4.50 the effect of the external roof blind on resultant temperatures between 8.00-17.00hrs is more clearly predicted. The external blind alone appears to reduce the resultant temperature by approximately 14°C for at least 4 hours over the mid-day period, though the temperatures are still above 30°C. Ventilation alone reduces resultant temperatures by approximately 9°C over the same period.

The combination of external blinds and ventilation reduces the resultant temperature further to 27°C or below for the whole of the daytime period. The cooling effect of blinds and ventilation extends into the evening period after the blinds have been opened.

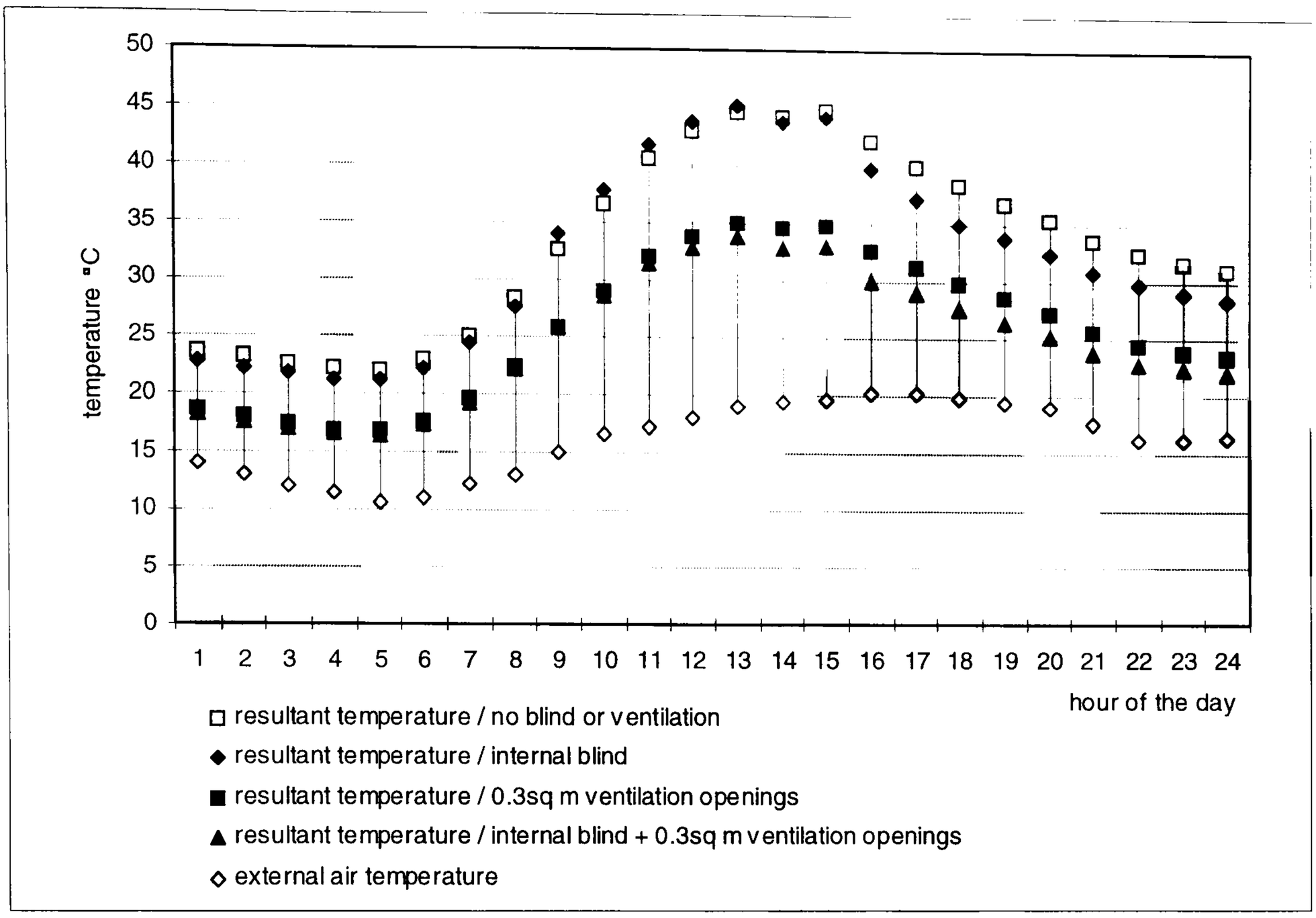


Figure 4.49 **The effect of internal medium roof blinds and ventilation on resultant temperatures in the integral, south facing, double glazed space**

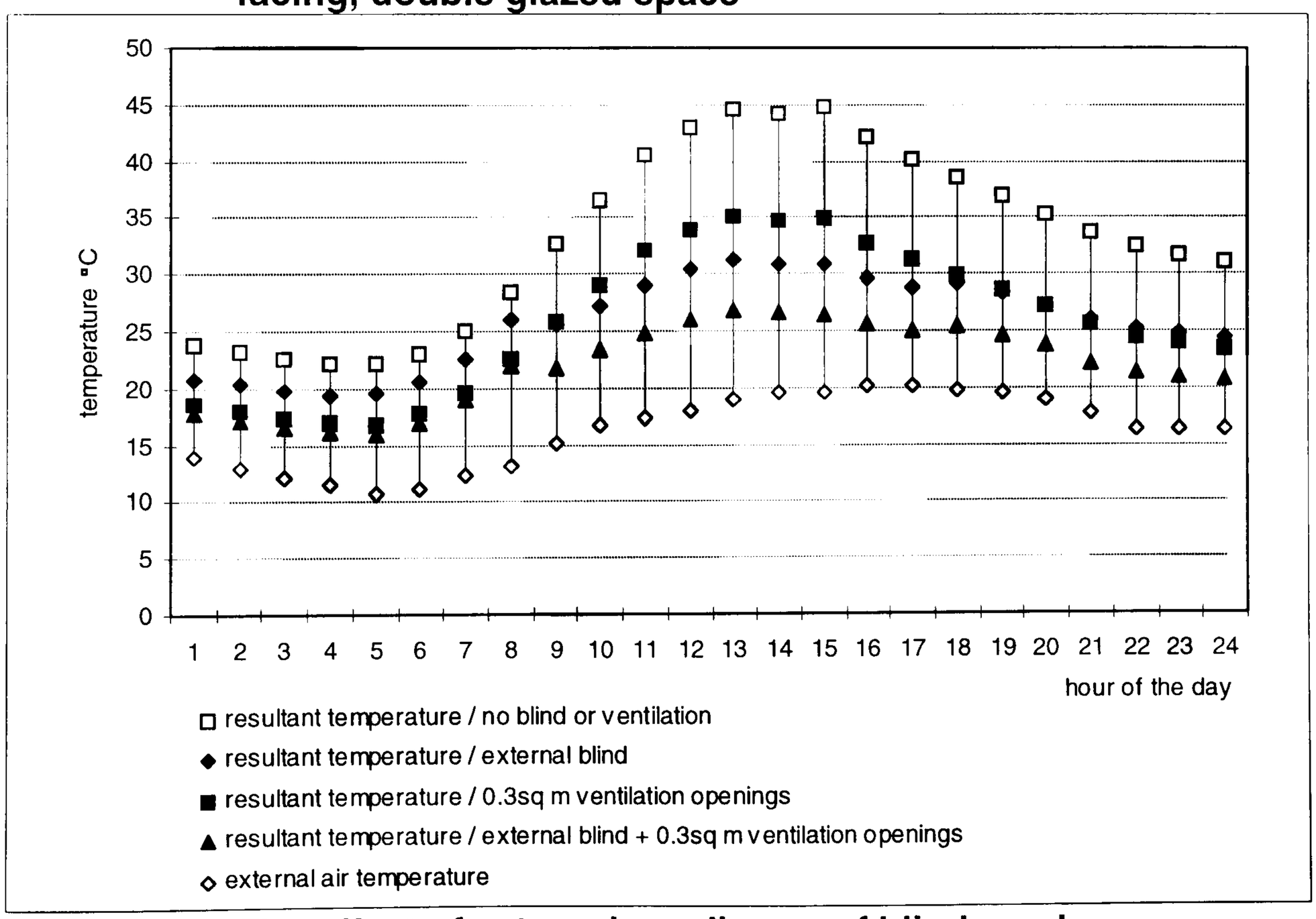


Figure 4.50 **The effect of external, medium roof blinds and ventilation on resultant temperatures in the integral, south facing, double glazed space**

4.07 Investigation of Thermal Comfort in the Glazed Spaces during the Winter Months

As discussed in Chapter 2.05 the human body's sensation of thermal comfort within a given space depends on the air temperature, radiant temperature, air movement and humidity in the space, together with the individual's clothing and level of activity.
Resultant temperature was used as the basis for the assessment of thermal comfort in the unheated glazed spaces. In the Tas program, resultant temperature is the average of air temperature and the mean radiant temperature of the surfaces of the space and is therefore a measure of the temperature perceived by the occupants.

Heated glazed spaces
In the thermal simulations of the heated glazed spaces, the set point for the heating system was set at 20°C, thus after the first hour of the heating period [during which the air temperature was being brought up to the set point] the air temperature within the space was maintained at 20°C for the remainder of the heating period. However the temperatures of the surfaces of the glazed space which would be losing heat, due to radiation, conduction and convection, would again affect the sensation of thermal comfort by the occupants.
In order to investigate the thermal comfort in the heated glazed spaces, several models were simulated for Day 359, 25th December, a day with no direct radiation and being very close to the winter solstice, low levels of diffuse radiation. [See also Appendix F]. The ambient temperature reached a maximum of 3.3 °C during hour 12 and had fallen to 1.2 °C by hour 18.
The heating period for a weekday was from 16.00 hours until 21.00hrs.

Table 4.18 **Mean radiant and resultant temperatures within the glazed spaces for hour 18** [17.00hrs -18.00hrs] **during the heated period** [ambient temperature 1.2°C]

	Integral		Semi-exposed		Exposed	
	mean radiant °C	resultant °C	mean radiant °C	resultant °C	mean radiant °C	resultant °C
north single	17.1	18.6	16.5	18.3	15.9	18.0
north double	17.6	18.8	17.1	18.6	16.7	18.3
north low E	18.2	19.1	17.7	18.9	17.4	18.7
south single	17.2	18.6	16.6	18.3	15.9	18.0
south double	17.8	18.9	17.2	18.6	16.7	18.4
south low E	18.3	19.2	17.8	18.9	17.6	18.8

Due to the absence of direct solar radiation during the daytime, the temperatures in the north and south orientations for any glazing type are very close. The mean radiant temperature and hence resultant temperature decrease with increasing exposure of the glazed space and to a lesser extent

with decreasing insulation value of the glazing. The resultant temperatures are within the thermal comfort range [16°C-27°C] in reality down draughts from glazing would lead to discomfort. In practice owners intending to heat a glazed space for use as additional living space would probably fit blinds which could reduce discomfort resulting from low surface temperatures. The mean radiant and resultant temperatures predicted for hour 12 of Day 359 are shown below.

Table 4.19 **Mean radiant and resultant temperatures within the glazed spaces at hour 12** [11.00hrs - 12.00hrs] **during the unheated period** [ambient temperature 3.3°C]

	Integral		Semi-exposed		Exposed	
	mean radiant °C	resultant °C	mean radiant °C	resultant °C	mean radiant °C	resultant °C
north single	10.6	9.9	8.5	7.8	7.3	6.5
north double	12.0	11.3	10.0	9.2	8.5	7.7
north low E	13.4	12.6	11.5	10.7	9.9	9.1
south single	10.9	10.2	8.7	7.9	7.4	6.6
south double	12.5	11.7	10.2	9.5	8.6	7.8
south low E	14.0	13.2	11.8	11.0	10.1	9.3

Unheated glazed spaces

The unheated models were also simulated for Day 359 and the temperatures recorded below. Mean radiant temperatures are higher than resultant temperatures at noon due to the effect of the diffuse solar radiation but at 18.00hrs they are generally equal in the exposed models and very similar in the integral models. The maximum resultant temperature, at noon, in the integral, south facing low E glazed space is 4.4°C below the minimum considered satisfactory for use of the space and that in the exposed, north facing single glazed space is 10°C below the minimum.

Table 4.20 **Mean radiant and resultant temperatures within the unheated glazed spaces at: hour 12 / hour 18**

	Integral		Semi-exposed		Exposed	
	mean radiant °C	resultant °C	mean radiant °C	resultant °C	mean radiant °C	resultant °C
north single	8.7 / 6.7	8.0 / 6.4	7.4 / 4.6	6.7 / 4.4	6.8 / 3.0	6.0 / 3.0
north double	9.7 / 8.0	9.1 / 7.7	8.5 / 5.9	7.8 / 5.7	7.8 / 4.0	7.0 / 4.0
north low E	10.9 /9.4	10.2 /9.0	9.6 / 6.8	8.9 / 6.6	8.9 / 5.1	8.1 / 5.0
south single	9.3 / 7.3	8.6 / 6.9	7.7 / 4.8	6.9 / 4.6	6.9 / 3.1	6.1 / 3.1
south double	10.8 /8.6	10.1 /8.2	8.5 / 6.5	7.4 / 6.3	8.0 / 4.2	7.2 / 4.2
south low E	12.3/10.6	11.6/10.1	10.3 /7.8	9.6 / 7.5	9.3 / 5.4	8.4 / 5.3

CHAPTER 5

Conclusions on the Study and Discussion of Further Work on the Design of Domestic Highly Glazed Spaces

Conclusions

Summary of the basis for the investigation

The purpose of this study was to investigate the effect of a range of variables on the design of glazed spaces in housing, in order to achieve a thermally comfortable environment while minimising the use of energy for heating and cooling. Previous studies of the design of domestic glazed spaces have concentrated on the performance of the space as a mechanism for the reduction of the space heating load of the parent house and hence a reduction in energy use. Many of these studies involved glazed spaces which, by their relationship with other rooms implied use as additional living space. Results from these studies did not provide conclusive evidence of energy savings and the use of the glazed spaces was often impaired by temperatures too high or too low for comfort.

A subsidiary study by the author of this thesis, included in Appendix A, investigated the design of a glazed space purely for the purpose of reducing the house space heating load. The study demonstrated the possibility of energy savings with careful design, aimed at maximising energy saving potential. The extremely high air temperatures within the glazed space resulting from this approach would however conflict with the requirements for thermal comfort, if such a space were to have an additional function as a living room.

Over the past twenty years or so, highly glazed spaces in the form of conservatories have become a popular form of addition to existing houses, though there has been scant regard within the conservatory supply industry for the poor quality of thermal and visual comfort provided within these spaces. In order to restore public confidence in the quality of their products, conservatory manufacturers and suppliers are now offering glazing specifications, shading blinds and energy consuming, heating and cooling devices in attempts to control the extremes of temperature and so improve thermal comfort.

This thesis acknowledges primarily the popularity of the glazed space as a well daylit living space and within this context investigates the effect on thermal comfort of three variables; the glazing specification, the orientation and the degree of integration of the glazed space with the house design [and hence the proportion of glazed to opaque construction].
As a secondary issue this thesis ackowledges the possibilities of the glazed space as an energy saving device but treats this as a subordinate role. In addition an assessment was made of the energy required to heat the glazed spaces to a comfortable temperature during certain periods of the day.
Thirdly, this study investigates the effect of location, shading and insulating blinds, fabric thermal storage and ventilation on the thermal performance of glazed spaces.

Summary of the method used for the investigation

An attempt has been made, in this thesis, to rationalise the investigation of the design of glazed spaces. Looking at previous studies involving the monitoring of existing conservatories, evaluation of thermal properties on a comparative basis is difficult due to the differences in such characteristics as physical form, materials, orientation, location, relationship with the parent building and pattern of use. By using computer based thermal simulation techniques for this study, the effect of the three, primary variables on the thermal perfomance of related glazed spaces has been investigated under identical conditions.

A house with a single storey glazed space was used as a development model. A range of related models were subsequently generated in which the same three-dimensional form of a two storey glazed space was used in three different relationships to a parent house. The models were not put forward as specific design solutions but as tools for assessing the performance of a variety of arrangements. Basic house models without glazed spaces were also derived from the original models to provide a comparison in terms of the heating load for a house, with and without a glazed space and also the effect of a glazed space on temperatures in adjoining rooms. Building constructions and materials in common usage in the house building industry and complying with the insulation requirements of the Building Regulations, [1991 edition] were assigned to the building elements of the house models. Data on domestic occupancy and heating patterns, infitration and incidental gains available in existing research work were used as a basis for the internal conditions for the zones of the thermal models.

Summary of the interpretation of the thermal simulation results

The results of the thermal simulations indicate that varying the three basic parameters; type of glazing orientation and degree of integration, produces a wide range of profiles of hours of comfortable resultant temperatures and heating loads in the glazed spaces but has a far less noticeable effect on the heating loads of the parent house. These results form an assessment of the thermal performance of the basic forms of the models, against which the effect of measures such as ventilation, shading and insulating blinds can be compared.

The results charts included in the text; the profiles of comfortable resultant temperatures and heating loads, provide a method for conveying basic information on a monthly and yearly basis about the thermal performance of unventilated glazed spaces of different construction and orientation.

The charts of the one day simulation results provide an insight into the thermal conditions experienced in the different forms of glazed space and the effect that ventilation, shading blinds and heating have on temperatures within the glazed spaces during specific weather conditions.

In using the simulation results, the following points need to be taken into account; the results depend on the accuracy of the thermal simulation programs, the data input into the programmes regarding building constructions and internal conditions and the weatherfile information. For the majority of the

simulations, weather data for the South-east region of the United Kingdom was used. North-west region weather data was also used for a small comparative study.

An assumption was made in the preparation of the models that the houses and glazed spaces were not overshadowed by other buildings or vegetation.

Specific Conclusions

There were eleven areas of investigation within this thesis and specific conclusions are drawn separately as follows;

Thermal comfort in the unshaded, unventilated and unheated glazed spaces

The assessment of thermal comfort within the glazed spaces was based on a range of recommended temperatures from existing research and relevant publications. The comfortable range for this study was established as being a minimum resultant temperature of 16°C and a maximum resultant temperature of 27°C. Resultant temperature, rather than air temperature, was used as the basis for temperature measurement in order to take into account the effect of the temperatures of surrounding surfaces, sensed in glazed enclosures. Resultant temperatures generated by the simulations were recorded throughout the day and evening [8.00hrs-23.00hrs Greenwich Meantime, with an adjustment for British Summertime] in order to assess the thermal comfort for the whole period in which the space could be used.
In addition to reference to the results charts for information on particular situations, general conclusions can also be drawn, as follows;

- Whatever the form, orientation or glazing type, the unshaded, unventilated, unheated, glazed space was only thermally comfortable for a quarter to a third of the hours of possible use, when simulated using the weatherfile for the south-east region of the United Kingdom. The ambient temperatures in the weatherfile rose above 27°C for only 25 hours during the course of the year.
- In the absence of ventilation, the higher the thermal insulating value of the glazing, the lower the number of comfortable hours experienced, over the course of a year.
- In the absence of ventilation, a southerly orientation provides fewer comfortable hours than a northerly orientation, over the course of a year.
- The temperature in a glazed space responds rapidly to incident solar radiation and high temperatures contribute significantly to discomfort.
- Glazing with higher thermal insulating properties can reduce the number of uncomfortable hours caused by low temperatures in March and October but not to any great extent in January, February and December.
- The increased number of comfortable hours in the months of lower levels of solar radiation, provided by double or low E glazing is not sufficient to

compensate for the discomfort caused during the months of high solar radiation.

- The greater the degree of integration of the glazed space with the house, [the greater the ratio of solid to glazed construction] the greater will be the discomfort due to high temperatures during June, July and August.
- For southerly orientations the greater the degree of integration with the house the greater the number of comfortable hours during the Spring and Autumn.
- Comfortable hours in the Winter months generally occur around mid-day. This would be appropriate for retired owners or home-workers but would be of limited use for owners working away from home during the daytime.

Space heating loads for the parent house with an unheated glazed space

The parent houses were heated to a set point of 20°C in the living rooms and 18 °C in other areas, for early mornings and evenings on weekdays and all day and evening at weekends.

- For the exposed design, the energy savings predicted in the space heating load for the house due to the presence of an unheated glazed space were minimal.

Assessing the effect of an unheated integral glazed space on the heating load for a house is difficult, since removing the space from the plan would result in an impractical house plan. However the following conclusion has been drawn;

- The space heating load for 110m^2 of accommodation is greater if the unheated glazed space is integrated into the accommodation than if it is external to the accommodation. This is due to the additional heat loss through the enlarged external envelope. This conclusion applies to all the orientations and glazing types simulated.

Space heating loads for the glazed spaces

The glazed spaces were all separated from the rest of the house by constructions complying with the requirements of the Building Regulations. There was no air movement between the glazed space and other zones in the model. The heating set-point in the glazed spaces was set at an air temperature of 20°C and the heating period was from late afternoon to early evening on weekdays [16.00-21.00hrs] and all day and evening at weekends [8.00-21.00hrs]. The heating pattern and set-point were established from previous research into the heating of conservatories and were set up in order to assess the space heating load for the glazed space, used as an additional living room.

In addition to reference to the results charts in the text, for information on particular situations, conclusions on the space heating loads for the glazed spaces can also be drawn, as follows;

- The importance of orientation, in reducing the heating load, increases with higher insulation properties of the glazing.

- The importance of integration of the glazed space into the parent building, in reducing the heating load, decreases with higher insulation properties of the glazing.
- Low E glazing would appear to provide the most economical solution in terms of energy usage for space heating but has the disadvantage of high capital cost.

The space heating load for the house with a heated glazed space

- Adding an exposed single storey glazed space, which is heated in the evenings and all day and evening at the weekends can increase the heating load for the house by approximately 70% with single glazing, 35% with double glazing and between 14% -19% with low E glazing.
- Orientation and location have a marginal effect on these percentages, though if heating had been applied on weekdays as well, the effect of solar radiation on the heating loads for southerly orientations may have been more noticeable.
- Adding an exposed two storey glazed space, which is heated in the evenings and all day and evening at the weekends, can increase the heating load for the house by approximately 102-117% with single glazing, 47-60% with double glazing and 24%-33% with low E glazing, from predictions using the south-east weatherfile. The percentage ranges are dependant on orientation.

Comparison of the space heating load for the house with a heated, integral glazed space against that for an identical volume enclosed in standard construction, [the 132m^2 basic model], in which the heating pattern for the zone replacing the glazed space is the same as for the glazed space zone, indicates that ;

- the space heating load for the integral glazed space model is no greater than that for the standard construction model in the east and west facing, low E glazed situations and for the south facing, double and low E glazed situations, though this situation could easily change with different patterns of occupancy, incidental heat gains and heating and ventilation patterns.

Overheating in adjoining rooms

During the yearly simulations for the unheated, unshaded, unventilated glazed spaces, the number of hours when air temperatures rose above 27°C were recorded during the daytime and evenings for the living room zones adjoining the glazed spaces and in the basic houses. Similarly the number of hours when air temperatures rose above 25°C were recorded overnight for the bedroom zones adjoining the glazed spaces and in the basic houses. Comparison of the results in the basic house with those adjoining the glazed spaces are as follows;

- overheating in adjoining rooms was exacerbated slightly by the presence of an unventilated, exposed glazed space. The problem was much more pronounced with the integral arrangement.

- The bedrooms adjoining the south facing, integral, low E glazed space experienced twice as many hours of uncomfortably high temperatures, overnight, as a similar bedrooms in the basic house model.
- Bedrooms, in particular, should not be ventilated solely through the glazed space.

Location

The single storey glazed space models and basic houses were simulated using both the south-east and the north-west UK weather data and the following conclusions were drawn from the results;

- the lower levels of solar radiation and lower ambient temperatures of the north-west weatherfile result in a greater overall number of comfortable hours in the glazed spaces when compared to simulation results using the south-east weatherfile.
- The distribution pattern of comfortable hours is different for the two regions, more of the comfortable hours occurring during British Summertime and fewer during Greenwich Meantime in the north west situation than in the south-east situation.
- Heating loads, for evening and weekend space heating patterns, are higher for glazed spaces in the north-west location than in the south-east location.

Buoyancy driven ventilation

The iterative process used in conjunction with the one-day thermal simulations made it possible to investigate the promotion of air change rates, varying with the difference between external air temperature and air temperature within the glazed spaces, in selected models.

- The results of these studies suggest that buoyancy driven ventilation can contribute significantly to the reduction in uncomfortably high resultant temperatures in glazed spaces, particularly as the proportion of solid to glazed wall surface area increases.

The iterative process described is time consuming and only two sizes for high and low level ventilation openings could be tested for the selected models. Computer based air flow simulation programmes are becoming available which would allow a more thorough investigation of this topic.

Airbricks were used in this study as an indication of achievable low level ventilation openings in an existing component. In practice a more aesthetically acceptable component with a draught proof, insulated shutter would probably be more acceptable. However the incorporation of materials other than glass into the glazed envelope will change the solar gain characteristics and the insulating properties of the envelope, particularly in the integral arrangement. Manual control of the ventilating system could be difficult in a changing thermal environment, such as a glazed space though the ventilators could possibly be left open for the Summer months. This would also have a cumulative effect on reducing temperatures as shown by the ventilation studies.

Insulating blinds

- The thermal simulations suggest that insulating blinds could be of some use in reducing heating loads in double and low E glazed spaces.Their use would depend on the development of a suitable material and efficient operating and fixing [possibly external] mechanisms. In purely financial terms, at present day energy costs, the capital cost of such a system would far outweigh the predicted savings.

The use of roof blinds to reduce overheating

- Previous work using test cells indicated that internal roof blinds were not suitable for reducing overheating problems in glazed spaces as they heat up with incident solar gain transmitted through the glazing and transfer heat by re-radiation to the surfaces of the room and to occupants and by warming the adjacent air. The results of the thermal simulation for an internal roof blind, in this study appear to reinforce this earlier finding. Further studies including the use of wall blinds in different forms and orientations of glazed space are needed to give a definitive answer on the usefulness of internal blinds in reducing high temperatures.

- Earlier studies have suggested that external blinds can be used to reduce high temperatures, as they reflect solar radiation before it can pass through glazing and so the resultant temperatures in a glazed space are less likely to reach uncomfortable levels. The results of the thermal simulation for an external roof blind in this study reinforce this, a substantial reduction in the maximum resultant temperature being achieved in an integral glazed space, on a day of high levels of solar radiation. Again a wider study is needed to investigate the effects of external blinds in other situations.

- The investigation of the use of blinds was extended to test the effect of a combination of blinds and ventilation. The use of an external blind in this way provides a further, appreciable reduction in the maximum resultant temperature when compared to the effect of the blind alone, bringing the resultant temperatures down to within the comfortable range for the whole of the day, even on a day of high solar radiation.

Increasing the thermal mass in order to control high temperatures

- The results of the study on increasing the thermal mass in the floor of the glazed space by replacing the carpet finish with a clay tiled finish were inconclusive. The storage and release of heat by the tiles appeared to have both positive and negative effects, depending on the time of day and year. The number of hours involved in any of these effects was negligible. This was possibly because in the original floor construction the carpet finish, being only a thin layer, was not isolating the thermal storage effect of the underlying screed and concrete slab to any great extent and therefore the change to a tiled floor finish had only a small effect on predicted resultant temperatures.

Thermal comfort in the glazed spaces during the Winter months

- The study of thermal comfort for a Winter day with no direct solar radiation and very low ambient temperatures, indicated the effect of reduced areas of glazing and the increased insulating value of the glazing, in improving the values of resultant temperatures under such conditions. However, even in the integral, south facing, low E glazed situation the maximum resultant temperature remained several degrees below the minimum considered suitable for the use of the space for any length of time.
- For the heated model under the same weather conditions, the simulation results indicated that a heating set point of 20°C was sufficient to offset low mean radiant temperatures and maintain resultant temperatures above the comfortable minimum. However, resultant temperatures are noted in the centre of the zone and therefore conditions would not be so comfortable close to the glass, particularly in the more exposed situations.
- For the heated model the intermittent heating input was sufficient to marginally raise resultant temperatures within the glazed spaces during the unheated periods, due to the thermal storage properties of the solid elements of construction. This effect was therefore more marked in the integral glazed spaces.

Overall conclusions on the results of the investigations

The use of computer based thermal simulation has provided a means of comparison of the form, orientation and glazing materials of glazed spaces on a far wider scale than previously available. The thermal simulation results reinforce some of the intuitive approaches to the design of glazed spaces developed by the small sample of architects responding to the questionnaire on such topics as orientation, overheating and ventilation.

The study also reinforces earlier research work which indicated very little energy saving due to the presence of a glazed space, though in this study the glazed space was only used in 'buffer mode' and no attempt was made to transfer heat from the glazed space to the parent house.

The increase in energy use for space heating found in this study, resulting from the heating of glazed spaces, reinforces earlier studies and provides a basis for comparison of energy use in different forms of glazed space.

The integral, low E glazed space appears to offer the best solution in limiting heat loss from a heated glazed space but has the disadvantage of long periods at uncomfortably high temperatures during hours when levels of solar radiation are high.

Discussion of future work on the regulation of the design of domestic scale, highly glazed spaces

When considering the design of glazed spaces, in particular the possible use of energy consuming systems to increase thermal comfort, the issue of occupant behaviour has to be taken into account. Studies have shown that some conservatory owners will expect to be able to use the space all year round, making use of heating, fans or air conditioning as necessary. Other owners will be prepared to use the glazed space when it is comfortable without the

additional use of energy. It could also be argued that the higher the insulating properties of the glazing and the greater the degree of integration with the rest of the house, the more likely the owners are to expect year round use.
These responses will largely depend on the capital expenditure required for the equipment and on the energy running costs of the systems, in relation to the owners disposable income. Concern about the global environment may also play a part, with awareness of the consequences of fuel use such as the consumption of finite resources, the production of pollutants and the possibility of resulting climate change, restraining this additional use of energy in the home.
It is difficult to predict whether conservatory owners would make use of external blinds or insulating shutters, if these were required by legislation. In regions of Europe, warmer than the United Kingdom, the ingress of solar radiation and ventilation air through window openings has traditionally been controlled by the use of slatted blinds and louvered shutters which form an integral part of the window installation. In the United Kingdom there is much less use of such systems in housing. The use of internal or external shutters as insulating and shading devices has died out during the course of this century and louvre blinds and lightweight curtaining tend to remain in place throughout the day, probably for reasons of privacy rather than shading.
In designing for a specific client, an architect can tailor the design of a glazed space to the clients requirements and the client can be made aware of the implications and limitations of the design. However if the house is later sold, the new owners requirements could be quite different and energy use increase as a result. When designing houses for the mass market, an architect or developer's designer has no way of knowing what the house buyer's attitude or requirements regarding a glazed space will be. Developers cannot be expected to inform prospective purchasers that part of the house they are buying will only be usable for a small proportion of the year.
In the conservatory industry, low temperatures have been identified as the major problem with glazed spaces and heating has been seen as the reason for energy use. Double, low E glazing and twin or triple walled polycarbonate sheeting have been put forward by conservatory manufacturers, in order to offset criticisms of low temperatures and reduce the need heating requirement. With the use of glazing with higher insulating properties, the problem of overheating is now becoming apparent and the use of fans and even air conditioning units recommended.
In terms of thermal comfort in glazed spaces the problem of high temperatures can to some extent be relieved by the opening of doors and windows if provided. However these type of openings do not necessarily promote appropriate or efficient air circulation and in many areas of the country it would be unwise from a security point of view to leave windows and doors open overnight or when the house was unoccupied.

An approach to the design and regulation of glazed spaces

Taking into account the fact that there is a demand for highly glazed spaces in housing and that some owners will use heating and cooling systems as necessary to maintain thermal comfort, a robust approach to the design of such spaces is required, in order to minimise the use of energy.

The regulation of the design of glazed spaces in order to conserve the use of fuel and power in housing has only recently been introduced into the Building Regulations and only on a very limited basis. The results of the thermal simulations in this thesis indicate that heating a single storey, north facing, single glazed space for a few hours on weekdays and all day at weekends can require an increase in energy use of 72% of the energy required for heating a similar house without a glazed space. Even in the 'best' single storey situation; heating, as above, a south facing, low E glazed space can result in an increase in energy use of up to l6%.

The orientation of a glazed space is often dictated by site considerations. The form and glazing can be chosen to suit this orientation. The findings of this thesis indicate that varying combinations of form, glazing and orientation provide different profiles of hours when the space would be comfortable to use. These hours can be extended by the use of natural ventilation and external shading. The findings also indicate that the heating requirement for glazed spaces can be reduced by the use of glazing with good insulating properties and by the form of the glazed space. The integral glazed space provides the benefits of a low heating requirement with the ability to respond to the potential for buoyancy driven ventilation. The limited area of glazing required for this form of glazed space means that the use of more expensive, but better insulating, glazing becomes an economic possibility.

The recently issued Part L of the Building Regulations, Conservation of fuel and power [Building Regulations(5)1995]. includes the Target U value method as a means of demonstrating compliance with the regulations on limiting heating loss from dwellings. Formulae, as shown below, are provided for the calculation of Target U values for comparison, as an upper limit, with the average U value for the external elements of the dwelling under consideration.

For a dwelling with a Standard Assessment Procedure Energy Rating rating of 60 or less;

$$\text{Target U value [maximum]} = \frac{(\text{total floor area} \times 0.57)}{(\text{total area of exposed elements})} + 0.36$$

For a dwelling with a Standard Assessment Procedure Energy Rating rating greater than 60;

$$\text{Target U value [maximum]} = \frac{(\text{total floor area} \times 0.64)}{(\text{total area of exposed elements})} + 0.4$$

For the house model, with the integral glazed space treated as being a heated volume within the external envelope of the dwelling, these Target U values would be **0.734 and 0.696 W/m^{2}K** . With the additional 10% allowance for the use of a gas fired condensing boiler, these limiting U values could be increased to **0.807 and 0.766 W/m^{2}K**

The average U value for comparison with the Target U value is achieved by calculating the rate of heat loss per degree [area x U value, W/K] for each external building element and then dividing the total rate of heat loss per degree by the total exposed surface area.
Working through this calculation as set out below, for a house with an integral low E glazed space, of any orientation, but of the form and dimensions of the Integral thermal simulation model, gives an average U value of **0.704 W/m^{2}K**

Thus the design as calculated, would comply with the requirements of the Building Regulations, the average U value being lower than the lowest Target U value for a house with a gas fired condensing boiler.

Calculation of the average U value for the house model with a heated integral low E glazed space

Element	exposed surface area, metres ^{2}	U value W/m^{2}K	rate of heat loss per degree, W/K
Roof	55.0	0.25	13.75
Floor	66.0 [including glazed space]	0.4	26.4
External walls	126.45	0.45	56.9
Windows and door	15.5	3.0 [double glazed]	46.5
Glazed wall	12.54	2.4 [low E glazed]	30.1
Glazed roof	12.0	2.4 [low E glazed]	28.8
Totals	287.49		202.45

Therefore the average U value = $\frac{202.45}{287.49}$ = 0.704 W/m^{2}K

The figures for the U values for double and low E glazing used in the calculation are taken from figures given in the regulations.

This calculation indicates that it is possible for a house with a glazed space within the heated envelope, of the form and dimensions of the Integral thermal model, to comply with the current regulations on limiting the heat loss from dwellings. A similar calculation for a house with an exposed, low E glazed space, of any orientation but of the form and dimensions used in the Exposed thermal simulation model, gives an average U value of **0.870 W/m^{2}K** and so this design would not comply with the regulations. The Target U value method also allows for solar gain from windows facing south[+ or - 30°] to be taken into account which would allow larger areas than those in the integral glazed space to be used within the limiting orientation.

It could be argued that this approach to the regulations, pushing compliance to the limits does not provide for energy efficient design and should only be used in exceptional circumstances and not as a general rule.
Successive revisions of the Building Regulations have increased the requirements for energy conservation in dwellings. If the Regulations become even more stringent in the future then it could be argued that highly glazed areas should not be allowed under any circumstances, on the basis that owners will possibly heat the spaces, resulting in increased energy usage.

The possibility that owners will also use energy for fans and possibly air conditioning units in order to control high temperatures will reinforce this argument.
Such stringent legislation is unlikely to be passed but the design of highly glazed spaces should be controlled so that the benefits of the well daylit space could still be enjoyed with minimal recourse to energy use.
Under these circumstances, in the best case scenario the area of glazing could be limited to reduce solar heat gain and heat loss while still providing brighter natural lighting than that found in standard living rooms. Glazing insulation value could be chosen to reduce heat loss relative to the orientation. Provision for natural ventilation would be built into the envelope of the space in order to reduce high temperatures. Owners would then accept that during December, January and February use of the glazed space would be limited by the weather conditions, but a sheltered semi-external environment would be available for short periods of use. By the use of external shading, reduced roof glazing area and ventilation, the number of hours of uncomfortably high temperatures could be reduced to a minimum. External roof blinds could also be used in order to reduce excessively high temperatures, if reliable components and controls were available.
In the worst case scenario, there will still be some owners of glazed spaces who wish to be able to use the space all year round and who will install heating and possibly cooling systems. At least in this situation measures to reduce the amount of energy use for such systems will be inherent in the envelope of the space and energy use will be kept to a minimum. In some circumstances the number of hours which could be improved could be so small as to negate the investment in energy dependant cooling devices.

Overall conclusions

This thesis has demonstrated that varying combinations of form, proportion of opaque to transparent elements, orientation and insulating properties of the glazing produce different levels of performance in terms of a datum level of comfortable hours for each combination and with no ventilation. The studies on buoyancy driven ventilation predict the response to ventilation which could be expected for certain situations. The iterative method used has now been overtaken by computer based software capable of the simulation of buoyancy driven ventilation.
This therefore leads to the conclusion that in the future, designs of domestic glazed spaces should incorporate a substantial proportion of solid elements, walls and possibly roofs and that the area of glazing should be limited depending on glazing type and orientation. The control of allowable areas of glazing will limit heat loss from the spaces and will reduce the need for space heating. The provision of high and low level ventilation openings is also essential in reducing uncomfortably high temperatures. This robust approach to the design of glazed spaces should be encouraged through the dissemination of information throughout the building industry or enforced by legislation.

The findings of this thesis indicate the course which legislative control of glazed spaces could take in order to avoid excessive energy consumption in glazed spaces in the future.
Further research work, computer based simulations and monitoring of built examples and possibly test cells would be needed to provide optimum proportions of solid to opaque elements for glazing of different insulation properties and to assess the full possibilities of buoyancy driven ventilation.
Although the private house building market has been used as a framework for this thesis the information is also relevant to the retrofit conservatory market and to small scale public buildings, such as schools, libraries and health centres.

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'This must be a most inconvenient
sitting room for the evening, in summer;
the windows are full west.'
Pride and Prejudice, 1813

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APPENDICES

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APPENDIX A

REPORT FOR SUTTON (HASTOE) HOUSING ASSOCIATION BY THE DEPARTMENT OF APPLIED ENERGY, CRANFIELD UNIVERSITY

THE THERMAL PERFORMANCE OF A SOLAR VENTILATION PREHEAT SYSTEM FOR TERRACED HOUSING IN SAFFRON WALDEN AND MILTON KEYNES

JULY 1994

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INTRODUCTION

Project Brief

To assess the likely performance of the solar preheating of ventilation air by a rooftop sunspace.
The evaluation should consider the solar contribution from the sunspace and in particular the best type of material and configuration to create additional thermal mass within the sunspace.
The following range of standard building components were put forward for evaluation:
hollow concrete blocks, engineering bricks, concrete paving slabs laid on spacers which would provide a balance of heat retention and air flow through to the back of the sunspace and thence to the Temovex ventilation unit.
Advice was requested regarding the configuration of the blocks with reference to the removal of air from the sunspace, from the base of the rear wall or from upper sections of the wall as well.

Initial Response

The response to this brief was to propose the use of the TAS, Thermal Analysis System, computer based software, in order to compare the effect of the design of the sunspace on the annual space heating load for a typical terrace of four houses. The tests would include a range of glazing materials and a variety of materials and arrangements for the thermal storage component, including storage in the rear wall of the sunspace.
Summer overheating, particularly overheating in the bedrooms would also be investigated.

Client Response to the Interim Presentation

After the presentation of initial findings on May 26th 1994, the client requested or added the following;
A check on the comparative effect of a concrete block or insulated rear wall on the temperatures achieved in the sunspace, including the summer period.
The effect of using aluminium foil sheeting on the insulated rear wall.
The effect of drawing the ventilation air through the sunspace, for the whole 24 hour period, on the heating requirement and on the incidence of condensation in the sunspace.
The inclusion of the results of investigations into the positioning of the thermal storage blocks in the back wall of the sunspace.
Single glazing would probably be used for the sunspace roof.

SETTING UP THE COMPUTER MODELS

Basic terrace

A model of the basic, south facing terrace of four houses was set up, based on the drawings supplied and the scheme brochure, for plot nos.1-4 at Auton Croft. This first model did not contain the Temovex ventilation unit or the roof sunspace. By performing a thermal simulation on this model for the whole year it was possible to obtain a base figure for the space heating load for the terrace of four houses against which the space heating load for the terrace with the addition of the ventilation preheat options could be compared.

Building constructions, for each of the different wall, floor and roof types encountered, were set up from the information supplied and from manufacturer's literature, where appropriate. see App.1

Each house was divided into three zones, depending on occupancy patterns, required temperatures and heat gains from equipment and lights as follows;
1 Ancillary areas, circulation spaces and bathroom.
2 Living areas, consisting of living room, dining room and kitchen.
3 Bedrooms, including the airing cupboard.

This first model did not contain the Temovex ventilation unit or the roof sunspace.
Internal conditions data were set up for each of the three zone types for weekdays and weekends Greenwich Meantime and for British Summertime. [GMT and BST] see App.3
The weekday conditions were based on intermittent occupation and a morning and evening heating period. The weekend conditions were based on all day occupation and heating.
Incidental gains from occupants were calculated for two adults and two children.

Basic terrace with Temovex ventilation unit

The basic terrace model was copied and an additional zone added, to represent the temovex ventilation unit in which air, drawn from outside and supplied to the living and bedroom zones is pre-,warmed by heat from return air drawn from the living and ancillary zones. Within the model air is transferred from the bedroom zones to the ancillary zones to complete the air movement path.
Initial simulations only took air from the ancillary and bedroom zones of two of the houses, as a first step in attempting to represent a 50% efficiency for the heat exchanger in the Temovex. [50% return / 33% efficiency]

After further reflection and calculations it was decided that the 50% level of efficiency was actually represented in the Tas model by the return of all the air from all the ancillary and living zones. [100% return / 50% efficiency]
A further attempt to represent a greater level of efficiency involved the return of 1.5 times the amount of air from the ancillary and living zones. Tas deals with this apparent anomaly by creating air at the same condition as the air in the receiving zone. [150% return / 62% efficiency]

Basic Model with Temovex and Sunspace

The basic model with Temovex was copied again and the roof level reconstructed to include the sunspace, based as closely as possible on the sunspace shown in the drawings supplied. Variations on this basic design were created in order to test out different materials and configurations.
The thermal mass was incorporated into the model by the use of hollow concrete blocks forming the floor or rear wall or both the floor and rear wall, The cavities in the blocks forming horizontal ducts in the floor and vertical ducts in the wall. The intention being that external air brought into the sunspace could be transferred to these ducts and from there to the Temovex unit, in order to simulate the drawing of air through the thermal storage material.
Different densities of concrete block were used in order to represent the differing types of material requested in the brief. Results from simulations using blocks at the two extremes of the range, the dense, 2000 kg/m^3, and pumice, 1140 kg/m^3, types are included in this report.
The hollow concrete blocks used were of 140mm thickness and were chosen from manufacturer's data.
With regard to the glazing to the sunspace roof, initial simulations were carried out for a range of glazing materials but after the meeting of 26th May 1994 the client stated that single glazing would most likely be used for the sunspace roof.
Side walls were constructed as for the external walls of the terrace.
The front wall was always constructed as for the rear wall in either solid blockwork or as an insulated timber framed wall. A further construction involving the addition of a layer of aluminium foil to the sunspace side of the insulated wall or floor construction was also investigated at the client's request.
See App.2

Weatherfile
The UK_southeast weatherfile was selected for the computer simulations.

AIR MOVEMENT REGIMES

The basic air movement regime for the terrace consists of a controlled ventilation system in which air is supplied to the dining area, lounge and bedrooms and exhaust air is withdrawn from the kitchen area and bathroom. The supply air, 350 m^3/hr, is pre-warmed by being brought in through the sunspace and passing through the blockwork ducts into the Temovex ventilation unit where its' temperature is raised again by heat transfer from the return air.
The sunspace can be by-passed in Summer to prevent air at uncomfortable temperatures being drawn into the houses.
In addition to the 24 hour operation of the preheated ventilation system two further regimes were also investigated.

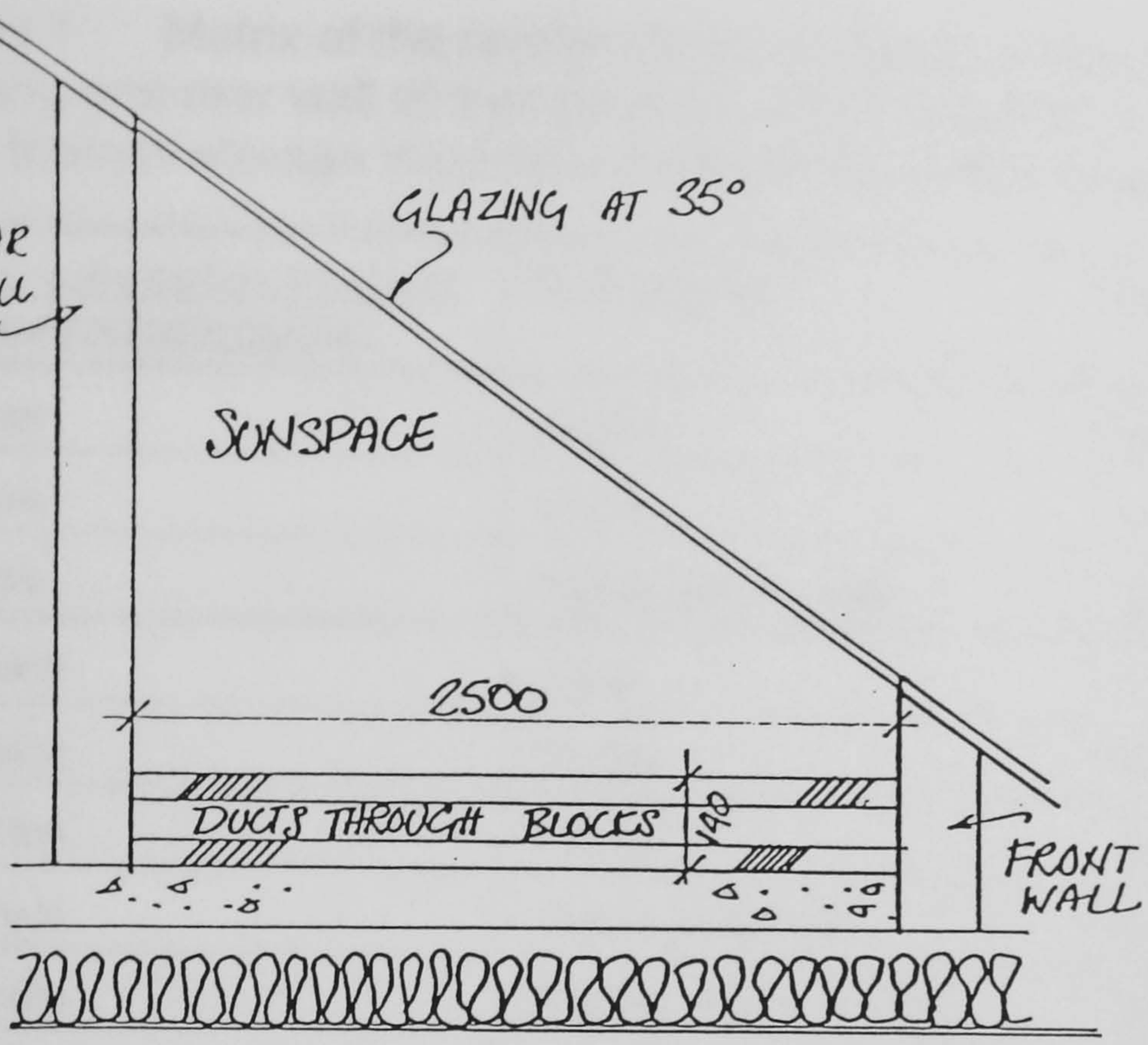
Sunspace shut off overnight

Weekday and weekend air movement;
0.00hrs - 8.000hrs external air brought directly into the Temovex, by-passing the sunspace.
8.00hrs - 24.00hrs external air brought in through the sunspace and passed through the blockwork ducts into the Temovex unit.
This regime was set up to avoid unnecessary depletion of the stored energy overnight, as drawing air into the sunspace will tend to bring the temperature of the thermal storage materials towards air temperature.

Air movement shut off during the daytime on weekdays

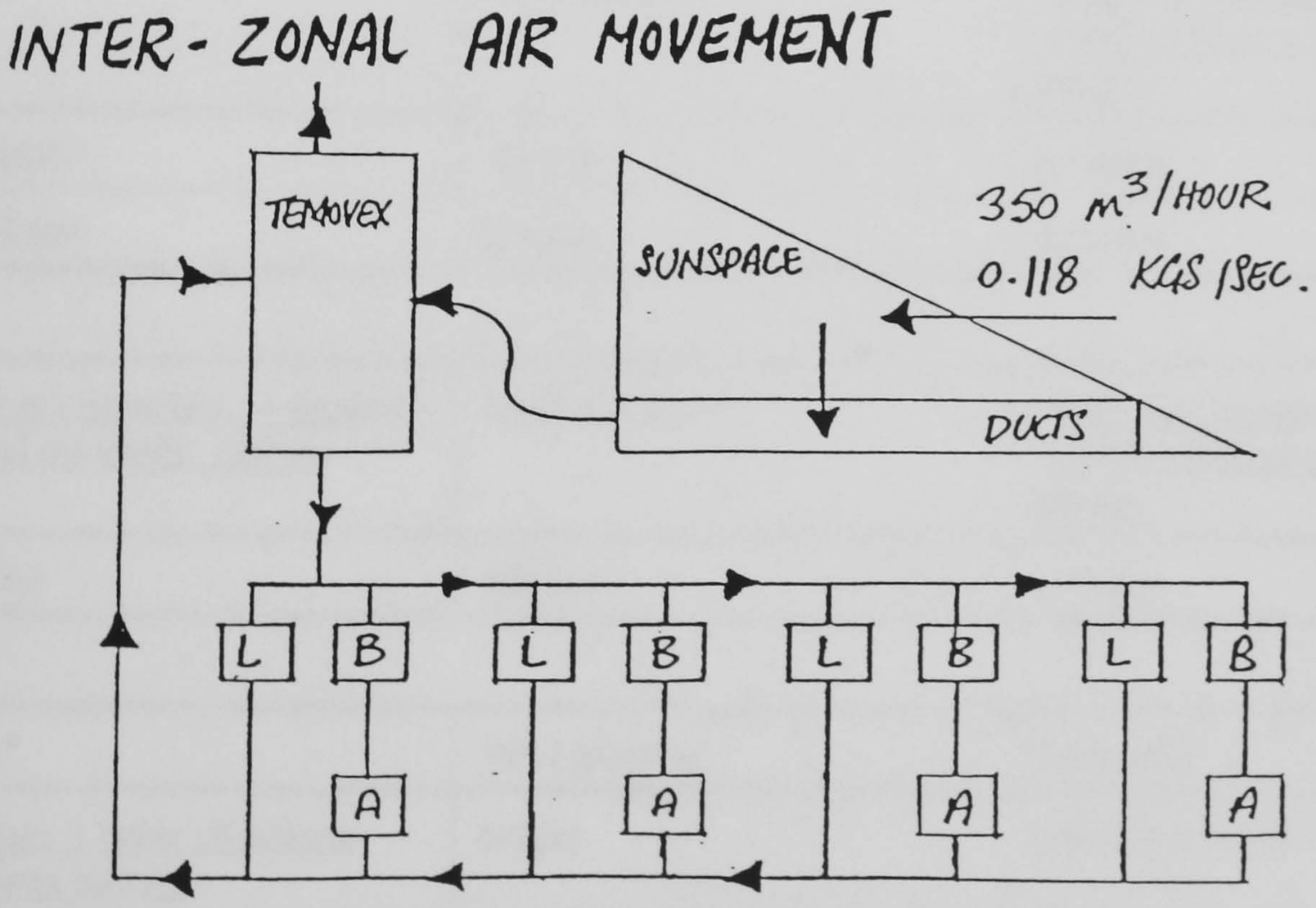
Weekday air movement;
0.00hrs - 8.00hrs external air brought directly into the Temovex
8.00hrs - 9.00hrs external air brought in through the sunspace and passed through the blockwork ducts into the Temovex.
9.00hrs -16.00hrs air in the sunspace recirculated between the sunspace and the blockwork ducts in order to enhance heat storage in the blocks.
16.00hrs -24.00hrs external air brought in through the sunspace and passed through the blockwork ducts into the Temovex.
In this regime the air movement through both the Temovex and the sunspace is shut down during the daytime and the air in the sunspace recirculated between the sunspace and the blockwork ducts in order to enhance heat storage in the blocks, whilst the houses were unoccupied during the daytime.

Weekend air movement;
0.00hrs -8.00hrs external air brought directly into the Temovex
8.00hrs - 24.00hrs external air brought in through the sunspace



SUNSPACE CONSTRUCTION

FOR ALTERNATIVE ARRANGEMENTS SEE TABLE 1.



A· Ancillary areas, circulation spaces and bathroom.
L· Living areas, consisting of living room, dining room and kitchen.
B· Bedrooms, including the airing cupboard.

Table 1 Matrix of the combinations of materials used for the floor, roof glazing and rear wall of sunspace for which simulations were perfomed. The thermal storage material is indicated by underlining.

Floor composition,1 layer of hollow concrete blocks	Roof glazing	Rear wall
dense	double	dense solid concrete blocks
dense	double	insulation
dense	double with aerogel	dense solid concrete blocks
pumice	single	dense solid concrete blocks
pumice	double	dense solid concrete blocks
pumice	double	insulation
pumice	double with low E	dense solid concrete blocks
pumice	double, lowE with argon	dense solid concrete blocks
pumice	double with aerogel	dense solid concrete blocks

Floor composition, 2 layers of hollow concrete blocks	Roof glazing	Rear wall
dense	double	dense concrete blocks

Floor	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks
insulation	double	pumice
insulation	single	pumice

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks
pumice	double	pumice

Floor	Roof glazing	Rear wall
pumice, 1 layer of hollow concrete blocks	single	insulation + foil
insulaton + foil	single	pumice, 1 layer of hollow concrete blocks

Table 2

Results for the annual space heating load for the basic terrace with the separate addition of theTemovex and the sunspace.

Air movement 0-24.00hrs as appropriate

	heating load, kWhs	%age reduction *
Basic terrace [no Temovex or sunspace]	7612	
Terrace with Temovex only [no sunspace] 50% return air to theTemovex, 33% efficiency	5062	33.5
Terrace with Temovex only [no sunspace] 100% return air to theTemovex, 50% efficiency	4087	46.3
Terrace with sunspace only [no Temovex] [dense hollow block floor /double glazed /dense wall]	5466	28.19
Terrace with sunspace only [no Temovex] [pumice hollow block floor /single glazed /insulated wall]	6062	20.4
Terrace with sunspace only [no Temovex] [insulated floor /single glazed / pumice hollow block wall	5957	21.7

* For Tables 1-7, '%age reduction' expresses the annual heating load for the model listed as a percentage of the annual heating load for the south facing basic terrace with no Temovex or sunspace, 7612 kWhs.

Table 3
Results for the annual space heating load with Temovex and sunspace

100% return air to the Temovex, 50% efficiency

Weekday and weekend air movement;
0.00hrs - 8.00hrs external air brought directly into the Temovex
8.00hrs - 24.00hrs external air brought in through the sunspace and blockwork ducts to the Temovex

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall	heating load, kWhs	%age reduction
dense	double	dense	3695	51.5
pumice	double	pumice	3654	52.0
dense	double	insulation	3608	52.6
pumice	double	insulation	3600	52.7
dense	single	dense	3767	50.5
pumice	single	pumice	3735	50.9
dense	single	insulation	3698	51.4
pumice	single	insulation	3693	51.5

Floor	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks	heating load, kWhs	%age reduction
insulation	single	pumice	3622	52.4

Table 4
Results for the annual space heating load with Temovex and sunspace

100% return air to the Temovex, 50% efficiency

Weekday and weekend air movement
0.00hrs - 24.00hrs external air brought in through the sunspace and blockwork ducts to the Temovex

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall	heating load, kWhs	%age reduction
pumice	single	insulation	3644	52.2

Floor	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks	heating load, kWhs	%age reduction
insulated	single	pumice	3590	52.8

Table5
Results for the annual space heating load with Temovex and sunspace

150% return air to the Temovex, 62% efficiency

Weekday and weekend air movement;
0.00hrs - 24.00hrs external air brought in through the sunspace and blockwork ducts to the Temovex

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall	heating load, kWhs	%age reduction
pumice	single	insulated	3206	57.9

Floor	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks	heating load, kWhs	%age reduction
insulated	single	pumice	3163	58.5

Table 6

Results for the annual space heating load with Temovex and sunspace

50% return air to the Temovex, 33% efficiency

Weekday and weekend air movement;
0.00hrs - 8.00hrs external air brought directly into the Temovex
8.00hrs - 24.00hrs external air brought in through the sunspace

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall	heating load, kWhs	%age reduction
dense	double	dense	4499	40.9
dense	double	insulation	4366	42.6
dense	double,aerogel	dense	4282	43.8
pumice	single	pumice	4574	39.9
pumice	double	pumice	4420	41.9
pumice	double	insulation	4343	43.0
pumice	double,lowE	pumice	4374	42.5
pumice	double,lowE,argon	pumice	4308	43.4
pumice	double,aerogel	pumice	4190	45.0

Floor composition, 2 layers of hollow concrete blocks	Roof glazing	Rear wall	heating load kWhs	%age reduction
dense	double	dense	4563	40.1

Table 7
Results for the annual space heating load with Temovex and sunspace
50% return air to the Temovex ,33% efficiency

Weekday air movement:
0.00hrs - 8.00hrs external air brought directly into the Temovex
8.00hrs - 9.00hrs external air brought in through the sunspace and blockwork ducts to the Temovex.
9.00hrs - 16.00hrs air in the sunspace recirculated between the sunspace and the blockwork ducts in order to enhance heat storage in the blocks.
No air movement through the Temovex between 9.00hrs and 16.00hrs.
16.00hrs - 24.00hrs air brought in through the sunspace and blockwork ducts to the Temovex.

Weekend air movement:
0.00hrs - 8.00hrs external air brought directly into the Temovex
8.00hrs - 24.00hrs external air brought in through the sunspace

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall	heating load, kWhs	%age reduction
dense	double	dense	3984	47.6
dense	double	insulation	3936	48.3
pumice	double	pumice	3882	49.0
pumice	double	insulation	3877	49.1

Floor	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks	heating load, kWhs	%age reduction
insulated	double	pumice	3802	50.1

Floor composition, 1 layer of hollow concrete blocks	Roof glazing	Rear wall composition, 1 leaf of hollow concrete blocks	heating load, kWhs	%age reduction
pumice	double	pumice	3877	49.1

Table 8

Results for the annual space heating load for the south-west facing models

South-west facing	heating load,kWhs	%age reduction [of 7945]
Basic terrace [no Temovex or sunspace]	7945	
Terrace with Temovex only [no sunspace] 50% return air to the Temovex, 33% efficiency Air movement 0-24 hrs	5281	33.5
Terrace with Temovex and sunspace 50% return air to the Temovex, 33% efficiency Air movement 0-8.00hrs in through Temovex 8.00-24.00hrs in through sunspace [pumice hollow block floor/double glazed/pumice wall]	4699	40.9

Table 9

Results for the annual space heating load for the south-east facing models

South-east facing	heating load,kWhs	%age reduction [of 7963]
Basic terrace [no Temovex or sunspace]	7963	
Terrace with Temovex only [no sunspace] 50% return air to the Temovex, 33% efficiency Air movement 0-24 hrs	5415	32.0
Terrace with Temovex and sunspace 50% return air to the Temovex, 33% efficiency Air movement 0-8.00hrs in through Temovex 8.00-24.00hrs in through sunspace [pumice hollow block floor/double glazed/pumice wall]	4864	38.9

CONCLUSIONS

1. The dwellings are highly insulated and therefore heating loads are low when compared to similar sized dwellings built to less stringent standards.
2. The ventilation heat recovery system provides a greater proportion of the energy savings than the roofspace collector. Table 2
3. Blockwork ducts built in pumice blocks [density 1140 kg/m^3] give fractionally higher energy savings than those built in dense blocks [density 2000 kg/m^3]. Table 3
4. Wall ducts give slightly higher energy savings than floor ducts. Table 3, Table 4, Table 5
5. Wall ducts are also more compatible with natural air flow - warm air rising the apex of the of the roof can then be pulled down through the ducts in the blocks into the Temovex.
6. For the wall or floor not formed from hollow blocks, a lightweight insulated construction gives slightly higher energy savings than a solid block wall or the concrete plank floor. Table 3
7. Neither a double layer of blockwork ducts in the floor nor blockwork ducts in the wall and floor give greater energy savings than other options investigated. Table 6, Table 7
8. The addition of a layer of foil to the surfaces of the sunspace does not appear to increase energy savings.
9. Improving the insulating properties of the glazing to the roofspace does not seem to give cost effective energy savings but single glazing may give rise to condensation problems. Table 3,Table 6
10. Removing air from the sunspace continually over the 24 hour period did not adversely affect energy savings. Compare Tables 3 and 4
11. Simulations indicated that uncomfortable air temperatures, in excess of 27°C, occurred in the bedrooms of the whole terrace, during the summer with the Temovex bringing in only external air. This could be reduced to more acceptable levels, less than 27°C, by increasing the infiltration rate into the bedrooms from 0.2ac/h to 2.0ac/h.
12. Bedrooms under the sunspace do not appear to overheat to a greater degree than other bedrooms in the terrace.
13. Extremely high temperatures can be reached in the sunspace during periods of high solar radiation. Increasing air change rates through the sunspace can counter this effect to a certain extent.

APPENDIX 1 to the sunspace report

Building constructions for the basic terrace

Ground floor
Soft - carpet finish on screed on 'Jetsuper' insulation slabs over a void with a blinding layer over the subsoil. U= 0.268W/m^2K
Hard - as above with vinyl tile finish U= 0.284W/m^2K

External wall
lightweight plaster on 100mm blockwork [block density 1400kg/m^3]
200mm mineral wool insulation [k=0.048W/mK], facing brickwork.
U= 0.210W/m^2K

Party wall
2 leaves of lightweight plaster on 100mm blockwork [block density 1400kg/m^3]
70mm cavity between

Party wall above ceiling level
2 leaves of 100mm blockwork [block density 640kg/m^3]
70mm cavity between U= 0.557W/m^2K

Internal block wall
lightweight plaster on 100mm blockwork [block density 1400kg/m^3]

Stud partition
plasterboard,2 leaves with 70mm cavity between

Insulated stud partition
plasterboard,2 leaves with 80mm glasswool insulation between

Ground floor ceiling
plasterboard, 200mm cavity, 20mm medium density particle board with carpet finish

First floor ceiling
plasterboard with 200mm glasswool insulation above U= 0.187W/m^2K

Front door
high density particle board, 2 layers with 30mm polyurethane insulation between U= 0.669W/m^2K

Windows
4mm Kappafloat / 10mm airspace /4mm clear float glass U= 1.959W/m^2K

APPENDIX 2 to the sunspace report

Building materials for the sunspace

Hollow blocks for the ducts in the wall and /or floor

	Dense Topcrete standard	Pumice Boral Edenhall
Thermal conductivity W/mK	1.130	0.400
Density kg/m^3	2000	1140
Specific heat capacity J/kgK	1000	1053

Wall blocks are backed by a 100mm layer of phenolic foam insulation, k = 0.018, W/mK

Floor blocks are laid on the concrete plank floor specified

Roof glazing

	U value W/m^{2}K
single, 6mm clear	5.253
double, 4mm clear/10 airspace/4mm clear	2.781
low E, 4mm Kappafloat/10 airspace/4mm clear	1.959
argon filled; 4mm Kappafloat/12 argon/4mmclear	1.455
aerogel; 6mm clear/16 aerogel/6mm clear	1.136

Other elements

Side walls of the sunspace - as for the external walls to the terrace.

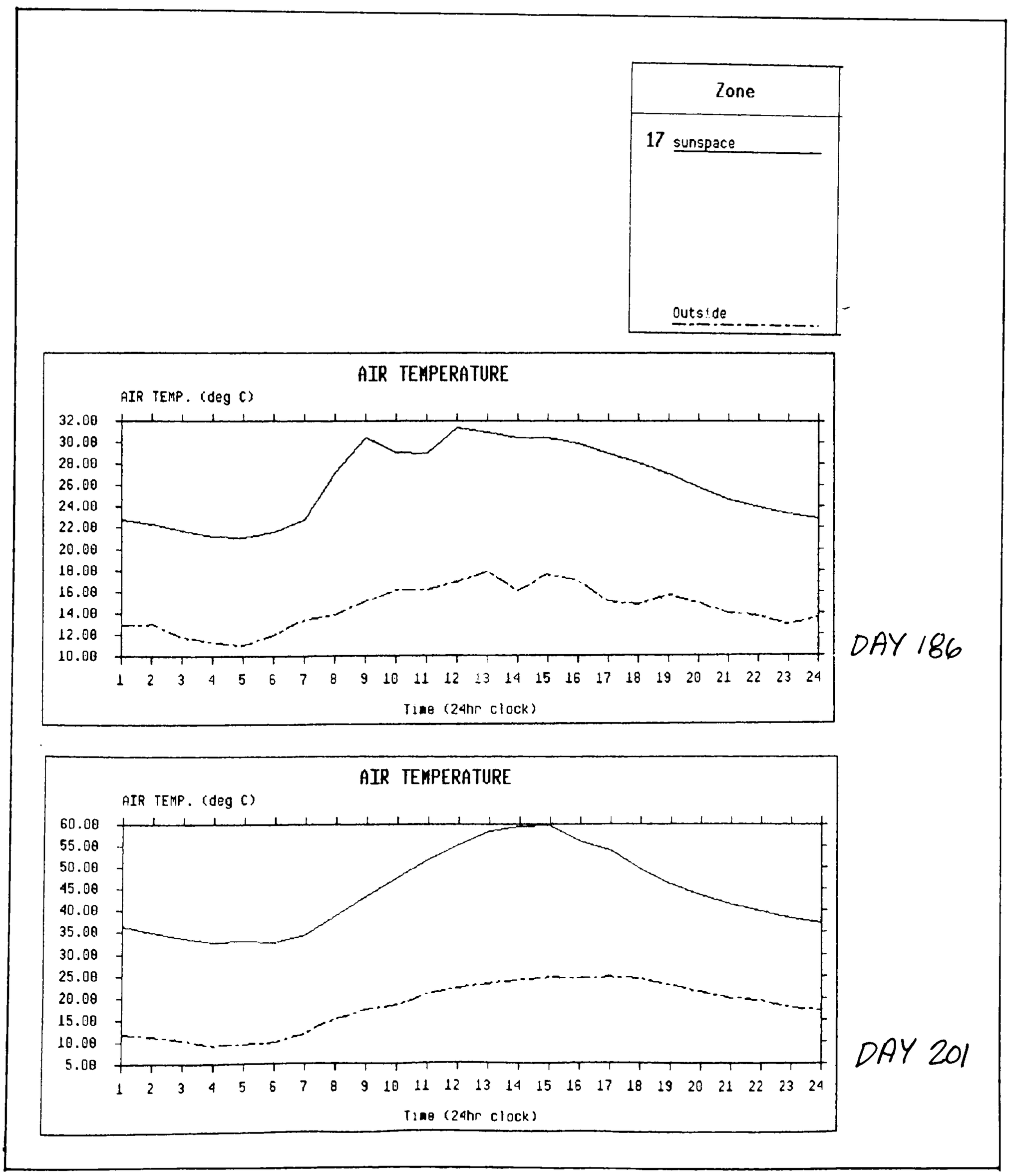
Rear and front walls of the sunspace - 200mm solid blocks with the same density as the hollow blocks.

Alternative front and rear walls and floor - 50mm phenolic foam insulation with a fibreboard backing layer, U = 0.314 W/m^{2}K.

APPENDIX 3 to the sunspace report

Internal conditions for the living areas, bedrooms and ancillary areas for an infiltration rate of 0.2 ac/h, with windows and doors closed, and 0.45 ac/h when doors would be opening and closing are included in this appendix. Similar internal conditions were used for the basic terrace but with infiltration rates of 0.75 ach and 1.0 ac/h to represent ventilation by opening windows, in the absence of the Temovex ventilation unit.

APPENDIX 4
Air Temperatures Reached in the Sunspace , Days 186 And 201



APPENDIX B

Questionnaire Issued to Architects

QUESTIONNAIRE TO ARCHITECTS
[Similar document for builders and developers]

Practice name:
Address :

Tel. :
Contact name :

Please supply the following information about any housing developments which your practice has designed in which highly glazed spaces, such as conservatories, have been incorporated into the house designs.
Copies of site and house plans would be greatly appreciated.

1. Total number of dwellings

2. Site area

3. House types

	Area	No. of persons	No. of this type on site	*conservatory
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

* Please indicate which of the house types included a conservatory or other highly glazed space.

4. Approximate dates of duration of project, from briefing to completion on site.

5. Reason for incorporating glazed space:

amenity [additional space, light]?

energy saving characteristics?

other reasons?

6. Were the glazed spaces designed and detailed by your practice or were 'off the peg' conservatories used?

7. Please give details of any mechanisms or construction methods incorporated in the design of the glazed spaces to control excessively high or low temperatures, condensation and glare.

8. Please give details of any feedback regarding the highly glazed spaces received from your client.

9. Please comment on your experience of conservatories or similar highly glazed spaces, particularly with respect to the following;

building costs / economics,

availability of technical information and design guidance,

any problems with Building Regulations,

whether you would advise a client to incorporate conservatories into future housing designs and why?

[continue on reverse if necessary]

APPENDIX C

The Report Generator Programs

- Monthly resultant temperatures in the glazed space [zone 1]
- Air temperatures in the living rooms [zone 2]
- Air temperatures in the bedrooms [zone 4]

Monthly resultant temperatures in the glazed space [zone 1]

```
open @1
dim zone[1]

# rt=resultant temperature
var rt.yd[].h[]
rt.yd[].h[]=read tres.zone[1].yd[].h[]

#to measure hours between 08.00 and 13.00, [9-13]gmt [8-12]bst are used since 9 represents
# what has happened in the ninth hour
#March and October have both GMT and BST hours

# JANUARY
# greenwich mean time hours when resultant temperature above 16
var rt1.yd[].h[]
rt1.yd[1:31].h[9:13]=rt.yd[1:31].h[9:13]-16
var rthours_over16_jan
rthours_over16_jan=countpos rt1.yd[1:31].h[9:13]
show rthours_over16_jan

# greenwich mean time hours when resultant temperature above 27
var rt2.yd[].h[]
rt2.yd[1:31].h[9:13]=rt.yd[1:31].h[9:13]-27
var rthours_over27_jan
rthours_over27_jan=countpos rt2.yd[1:31].h[9:13]
show rthours_over27_jan

#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_jan
rthours_comfort_jan=rthours_over16_jan-rthours_over27_jan
show rthours_comfort_jan

#FEBRUARY
# greenwich mean time hours when resultant temperature above 16
var rt3.yd[].h[]
rt3.yd[32:59].h[9:13]=rt.yd[32:59].h[9:13]-16
var rthours_over16_feb
rthours_over16_feb=countpos rt3.yd[32:59].h[9:13]
show rthours_over16_feb

# greenwich mean time hours when resultant temperature above 27
var rt4.yd[].h[]
rt4.yd[32:59].h[9:13]=rt.yd[32:59].h[9:13]-27
var rthours_over27_feb
rthours_over27_feb=countpos rt4.yd[32:59].h[9:13]
show rthours_over27_feb

#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_feb
rthours_comfort_feb=rthours_over16_feb-rthours_over27_feb
show rthours_comfort_feb

#MARCH
# greenwich mean time hours when resultant temperature above 16
var rt5.yd[].h[]
rt5.yd[60:83].h[9:13]=rt.yd[60:83].h[9:13]-16
var rthours_over16_gmar
rthours_over16_gmar=countpos rt5.yd[60:83].h[9:13]

# greenwich mean time hours when resultant temperature above 27
var rt6.yd[].h[]
rt6.yd[60:83].h[9:13]=rt.yd[60:83].h[9:13]-27
var rthours_over27_gmar
rthours_over27_gmar=countpos rt6.yd[60:83].h[9:13]

#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_gmar
rthours_comfort_gmar=rthours_over16_gmar-rthours_over27_gmar
```

```
# british summertime hours when resultant temperature above 16
var rt7.yd[].h[]
rt7.yd[84:90].h[8:12]=rt.yd[84:90].h[8:12]-16
var rthours_over16_bmar
rthours_over16_bmar=countpos rt7.yd[84:90].h[8:12]

# british summertime hours when resultant temperature above 27
var rt8.yd[].h[]
rt8.yd[84:90].h[8:12]=rt.yd[84:90].h[8:12]-27
var rthours_over27_bmar
rthours_over27_bmar=countpos rt8.yd[84:90].h[8:12]

# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_bmar
rthours_comfort_bmar=rthours_over16_bmar-rthours_over27_bmar

# addition of bst and gmt hours above 16
var rthours_over16_mar
rthours_over16_mar=rthours_over16_bmar+rthours_over16_gmar
show rthours_over16_mar

# addition of bst and gmt hours above 27
var rthours_over27_mar
rthours_over27_mar=rthours_over27_bmar+rthours_over27_gmar
show rthours_over27_mar

#comfort hours-hours when air temperature above 16 minus hours above 27
var rthours_comfort_mar
rthours_comfort_mar=rthours_over16_mar-rthours_over27_mar
show rthours_comfort_mar

#APRIL  NB numbering of rt variable changes to a,b,c,etc
# british summertime hours when resultant temperature above 16
var rt9.yd[].h[]
rt9.yd[91:120].h[8:12]=rt.yd[91:120].h[8:12]-16
var rthours_over16_apr
rthours_over16_apr=countpos rt9.yd[91:120].h[8:12]
show rthours_over16_apr
# british summertime hours when resultant temperature above 27
var rta.yd[].h[]
rta.yd[91:120].h[8:12]=rt.yd[91:120].h[8:12]-27
var rthours_over27_apr
rthours_over27_apr=countpos rta.yd[91:120].h[8:12]
show rthours_over27_apr
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_apr
rthours_comfort_apr=rthours_over16_apr-rthours_over27_apr
show rthours_comfort_apr

#MAY
# british summertime hours when resultant temperature above 16
var rtb.yd[].h[]
rtb.yd[121:151].h[8:12]=rt.yd[121:151].h[8:12]-16
var rthours_over16_may
rthours_over16_may=countpos rtb.yd[121:151].h[8:12]
show rthours_over16_may
# british summertime hours when resultant temperature above 27
var rtc.yd[].h[]
rtc.yd[121:151].h[8:12]=rt.yd[121:151].h[8:12]-27
var rthours_over27_may
rthours_over27_may=countpos rtc.yd[121:151].h[8:12]
show rthours_over27_may
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_may
rthours_comfort_may=rthours_over16_may-rthours_over27_may
show rthours_comfort_may
```

```
#JUNE
# british summertime hours when resultant temperature above 16
var rtd.yd[].h[]
rtd.yd[152:181].h[8:12]=rt.yd[152:181].h[8:12]-16
var rthours_over16_jun
rthours_over16_jun=countpos rtd.yd[152:181].h[8:12]
show rthours_over16_jun
# british summertime hours when resultant temperature above 27
var rte.yd[].h[]
rte.yd[152:181].h[8:12]=rt.yd[152:181].h[8:12]-27
var rthours_over27_jun
rthours_over27_jun=countpos rte.yd[152:181].h[8:12]
show rthours_over27_jun
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_jun
rthours_comfort_jun=rthours_over16_jun-rthours_over27_jun
show rthours_comfort_jun

#JULY
# british summertime hours when resultant temperature above 16
var rtf.yd[].h[]
rtf.yd[182:212].h[8:12]=rt.yd[182:212].h[8:12]-16
var rthours_over16_jul
rthours_over16_jul=countpos rtf.yd[182:212].h[8:12]
show rthours_over16_jul
# british summertime hours when resultant temperature above 27
var rtg.yd[].h[]
rtg.yd[182:212].h[8:12]=rt.yd[182:212].h[8:12]-27
var rthours_over27_jul
rthours_over27_jul=countpos rtg.yd[182:212].h[8:12]
show rthours_over27_jul
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_jul
rthours_comfort_jul=rthours_over16_jul-rthours_over27_jul
show rthours_comfort_jul

#AUGUST
# british summertime hours when resultant temperature above 16
var rth.yd[].h[]
rth.yd[213:243].h[8:12]=rt.yd[213:243].h[8:12]-16
var rthours_over16_aug
rthours_over16_aug=countpos rth.yd[213:243].h[8:12]
show rthours_over16_aug
# british summertime hours when resultant temperature above 27
var rtj.yd[].h[]
rtj.yd[213:243].h[8:12]=rt.yd[213:243].h[8:12]-27
var rthours_over27_aug
rthours_over27_aug=countpos rtj.yd[213:243].h[8:12]
show rthours_over27_aug
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_aug
rthours_comfort_aug=rthours_over16_aug-rthours_over27_aug
show rthours_comfort_aug

#SEPTEMBER
# british summertime hours when resultant temperature above 16
var rtk.yd[].h[]
rtk.yd[244:273].h[8:12]=rt.yd[244:273].h[8:12]-16
var rthours_over16_sep
rthours_over16_sep=countpos rtk.yd[244:273].h[8:12]
show rthours_over16_sep
# british summertime hours when resultant temperature above 27
var rtm.yd[].h[]
rtm.yd[244:273].h[8:12]=rt.yd[244:273].h[8:12]-27
var rthours_over27_sep
rthours_over27_sep=countpos rtm.yd[244:273].h[8:12]
show rthours_over27_sep
# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_sep
rthours_comfort_sep=rthours_over16_sep-rthours_over27_sep
show rthours_comfort_sep
```

```
#OCTOBER
# british summertime hours when resultant temperature above 16
var rtn.yd[].h[]
rtn.yd[274:293].h[8:12]=rt.yd[274:293].h[8:12]-16
var rthours_over16_boct
rthours_over16_boct=countpos rtn.yd[274:293].h[8:12]

# british summertime hours when resultant temperature above 27
var rto.yd[].h[]
rto.yd[274:293].h[8:12]=rt.yd[274:293].h[8:12]-27
var rthours_over27_boct
rthours_over27_boct=countpos rto.yd[274:293].h[8:12]

# british summertime hours when resultant temperature above 16 minus hours above 27
var rthours_comfort_boct
rthours_comfort_boct=rthours_over16_boct-rthours_over27_boct

# greenwich mean time hours when resultant temperature above 16
var rtp.yd[].h[]
rtp.yd[294:304].h[9:13]=rt.yd[294:304].h[9:13]-16
var rthours_over16_goct
rthours_over16_goct=countpos rtp.yd[294:304].h[9:13]

# greenwich mean time hours when resultant temperature above 27
var rtq.yd[].h[]
rtq.yd[294:304].h[9:13]=rt.yd[294:304].h[9:13]-27
var rthours_over27_goct
rthours_over27_goct=countpos rtq.yd[294:304].h[9:13]

#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_goct
rthours_comfort_goct=rthours_over16_goct-rthours_over27_goct

# addition of bst and gmt hours above 16
var rthours_over16_oct
rthours_over16_oct=rthours_over16_boct+rthours_over16_goct
show rthours_over16_oct
# addition of bst and gmt hours above 27
var rthours_over27_oct
rthours_over27_oct=rthours_over27_boct+rthours_over27_goct
show rthours_over27_oct
#comfort hours-hours when air temperature above 16 minus hours above 27
var rthours_comfort_oct
rthours_comfort_oct=rthours_over16_oct-rthours_over27_oct
show rthours_comfort_oct


#NOVEMBER
# greenwich mean time hours when resultant temperature above 16
var rtr.yd[].h[]
rtr.yd[305:334].h[9:13]=rt.yd[305:334].h[9:13]-16
var rthours_over16_nov
rthours_over16_nov=countpos rtr.yd[305:334].h[9:13]
show rthours_over16_nov
# greenwich mean time hours when resultant temperature above 27
var rts.yd[].h[]
rts.yd[305:334].h[9:13]=rt.yd[305:334].h[9:13]-27
var rthours_over27_nov
rthours_over27_nov=countpos rts.yd[305:334].h[9:13]
show rthours_over27_nov
#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_nov
rthours_comfort_nov=rthours_over16_nov-rthours_over27_nov
show rthours_comfort_nov
```

```
#DECEMBER
# greenwich mean time hours when resultant temperature above 16
var rtt.yd[].h[]
rtt.yd[335:365].h[9:13]=rt.yd[335:365].h[9:13]-16
var rthours_over16_dec
rthours_over16_dec=countpos rtt.yd[335:365].h[9:13]
show rthours_over16_dec
# greenwich mean time hours when resultant temperature above 27
var rtu.yd[].h[]
rtu.yd[335:365].h[9:13]=rt.yd[335:365].h[9:13]-27
var rthours_over27_dec
rthours_over27_dec=countpos rtu.yd[335:365].h[9:13]
show rthours_over27_dec
#greenwich meantime hours when resultant temp above 16 minus hours above 27
var rthours_comfort_dec
rthours_comfort_dec=rthours_over16_dec-rthours_over27_dec
show rthours_comfort_dec

do rtcomfort_month813_format @1 @2 @3 @4 @5 @6
open_out rt
write rthours_over16_jan, rthours_over27_jan, rthours_comfort_jan, &
      rthours_over16_feb, rthours_over27_feb, rthours_comfort_feb, &
      rthours_over16_mar, rthours_over27_mar, rthours_comfort_mar, &
      rthours_over16_apr, rthours_over27_apr, rthours_comfort_apr, &
      rthours_over16_may, rthours_over27_may, rthours_comfort_may, &
      rthours_over16_jun, rthours_over27_jun, rthours_comfort_jun, &
      rthours_over16_jul, rthours_over27_jul, rthours_comfort_jul, &
      rthours_over16_aug, rthours_over27_aug, rthours_comfort_aug, &
      rthours_over16_sep, rthours_over27_sep, rthours_comfort_sep, &
      rthours_over16_oct, rthours_over27_oct, rthours_comfort_oct, &
      rthours_over16_nov, rthours_over27_nov, rthours_comfort_nov, &
      rthours_over16_dec, rthours_over27_dec, rthours_comfort_dec
```

Air temperatures in the living rooms [zone 2]

```
 open @1
dim zone[2]

# at=air temperature
var at.yd[].h[]
at.yd[].h[]=read t.zone[2].yd[].h[]

# british summertime hours when air temperature above 25
var at1.yd[].h[]
at1.yd[84:293].h[6:22]=at.yd[84:293].h[6:22]-25
var athours_over25_bst
athours_over25_bst=countpos at1.yd[84:293].h[6:22]
show athours_over25_bst

# greenwich mean time hours when air temperature above 25
var at2.yd[].h[]
at2.yd[294:83].h[7:23]=at.yd[294:83].h[7:23]-25
var athours_over25_gmt
athours_over25_gmt=countpos at2.yd[294:83].h[7:23]
show athours_over25_gmt

# addition of bst and gmt hours above 25
var athours_over25_year
athours_over25_year=athours_over25_bst+athours_over25_gmt
show athours_over25_year

# british summertime hours when resultant temperature above 26
var at3.yd[].h[]
at3.yd[84:293].h[6:22]=at.yd[84:293].h[6:22]-26
var athours_over26_bst
athours_over26_bst=countpos at3.yd[84:293].h[6:22]
show athours_over26_bst

# greenwich mean time hours when air temperature above 26
var at4.yd[].h[]
at4.yd[294:83].h[7:23]=at.yd[294:83].h[7:23]-26
var athours_over26_gmt
athours_over26_gmt=countpos at4.yd[294:83].h[7:23]
show athours_over26_gmt

# addition of bst and gmt hours above 26
var athours_over26_year
athours_over26_year=athours_over26_bst+athours_over26_gmt
show athours_over26_year

# british summertime hours when airtemperature above 27
var at5.yd[].h[]
at5.yd[84:293].h[6:22]=at.yd[84:293].h[6:22]-27
var athours_over27_bst
athours_over27_bst=countpos at5.yd[84:293].h[6:22]
show athours_over27_bst

# greenwich mean time hours when air temperature above 27
var at6.yd[].h[]
at6.yd[294:83].h[7:23]=at.yd[294:83].h[7:23]-27
var athours_over27_gmt
athours_over27_gmt=countpos at6.yd[294:83].h[7:23]
show athours_over27_gmt

# addition of bst and gmt hours above 27
var athours_over27_year
 athours_over27_year=athours_over27_bst+athours_over27_gmt
 show athours_over27_year

 do atchecks2_format @1 @2 @3 @4 @5 @6
 open_out atchecks
 write athours_over25_bst, athours_over25_gmt, athours_over25_year, athours_
 close_out
 /prfo atchecks
```

Air temperatures in the bedrooms [zone 4]

```
open @1
dim zone[4]

# at=air temperature
var at.yd[].h[]
at.yd[].h[]=read t.zone[4].yd[].h[]

# british summertime hours when air temperature above 25
var at1.yd[].h[]
at1.yd[84:293].h[22:7]=at.yd[84:293].h[22:7]-25
var athours_over25_bst
athours_over25_bst=countpos at1.yd[84:293].h[22:7]
show athours_over25_bst

# greenwich mean time hours when air temperature above 25
var at2.yd[].h[]
at2.yd[294:83].h[23:8]=at.yd[294:83].h[23:8]-25
var athours_over25_gmt
athours_over25_gmt=countpos at2.yd[294:83].h[23:8]
show athours_over25_gmt

# addition of bst and gmt hours above 25
var athours_over25_year
athours_over25_year=athours_over25_bst+athours_over25_gmt
show athours_over25_year

# british summertime hours when resultant temperature above 26
var at3.yd[].h[]
at3.yd[84:293].h[22:7]=at.yd[84:293].h[22:7]-26
var athours_over26_bst
athours_over26_bst=countpos at3.yd[84:293].h[22:7]
show athours_over26_bst

# greenwich mean time hours when air temperature above 26
var at4.yd[].h[]
at4.yd[294:83].h[23:8]=at.yd[294:83].h[23:8]-26
var athours_over26_gmt
athours_over26_gmt=countpos at4.yd[294:83].h[23:8]
show athours_over26_gmt

# addition of bst and gmt hours above 26
var athours_over26_year
athours_over26_year=athours_over26_bst+athours_over26_gmt
show athours_over26_year

# british summertime hours when airtemperature above 27
var at5.yd[].h[]
at5.yd[84:293].h[22:7]=at.yd[84:293].h[22:7]-27
var athours_over27_bst
athours_over27_bst=countpos at5.yd[84:293].h[22:7]
show athours_over27_bst

# greenwich mean time hours when air temperature above 27
var at6.yd[].h[]
at6.yd[294:83].h[23:8]=at.yd[294:83].h[23:8]-27
var athours_over27_gmt
athours_over27_gmt=countpos at6.yd[294:83].h[23:8]
show athours_over27_gmt

# addition of bst and gmt hours above 27
var athours_over27_year
athours_over27_year=athours_over27_bst+athours_over27_gmt
show athours_over27_year

do atchecks2_format @1 @2 @3 @4 @5 @6
open_out atchecks
write athours_over25_bst, athours_over25_gmt, athours_over25_year, athours_
close_out
/prfo atchecks
```

APPENDIX D

Sources Used in the Compilation of the Internal Conditions Datasheets

- Heat gains from occupants
- Heat gains from lighting
- Heat gains from equipment and cooking
- Heat gains from water heating systems
- Infiltration rates
- Space heating

Heat gains from occupants

For the purposes of this study, a family occupying a 90m^2 house was assumed to consist of 2 adults and 2 children. A family occupying a 110m^2 house was assumed to consist of 2 adults and 3 children. The sensible and latent heat emissions from the occupants used in the Internal Conditions datasheets are shown below. The daytime and evening rates were used mainly in Zone 2 - Living rooms, but a small proportion was allocated to bedrooms in the early evenings and during weekends

	Sensible heat emissions Watts / m^2	Latent heat emissions Watts / m^2
Daytime and Evenings [light work]	9.8	3.9
Overnight [sleeping]	7.7	4.1

These figures have been calculated from the recommendations proposed in unpublished work conducted for the Building Research Establishment [BAeSEMA Ltd,1992], on the estimation of heat gains from occupants, [and household equipment] for use in thermal simulations, as shown below.

		Sensible heat emissions Watts	Latent heat emissions Watts
Daytime	man	100	40
"	woman	85	34
"	child	75	30
Night	man	75	40
"	woman	64	34
"	child	56	30

In arriving at the above values BAeSEMA Ltd used the daytime values for mean sensible and latent emissions for "light work", and the nightime values for "seated at rest", at 24°C, to allow for the effect of bedclothes as listed in Table A1.1 of the CIBSE Guide, Volume A : Design Data,[CIBSE, 1986].

Heat gains from lighting

From personal observation, a 100 Watt tungsten light bulb adequately lights a room of floor area of 10m^2. This gives a figure for sensible heat gain from lights of 10 W/m^2 ,assuming that the whole zone to which this is applied is well lit. Where a zone contains several rooms, some of which will be lit and the rest unlit, an appropriate fraction of this figure has been used to give a more accurate representation.

Heat gains from equipment

Values for heat gains from domestic appliances, household equipment and cooking on which the figures in the internal conditions datasheets were based,

have again been taken largely from the work conducted for the Building Research Establishment. [BAeSEMA Ltd,1992], and are included overleaf and in the lower table on this page.
Output from appliances, in use at specific times of day, were added together and divided by the average area of the living room zones [40m^2] for the 90m^2 and 110m^2 house types, to give the Watts/m^2 figures entered in the datasheets for Zone 2, and shown below;

Occupation period	Equipment	Total gains in Watts/m^2 sensible	latent
Background	fridge/freezer	2.0	
Breakfast period	fridge/freezer hob for 0.25hrs kettle for 0.25hrs	7.5	1.5
Afternoon period	fridge/freezer television hob/oven for 1hr	36.0 GMT 12.0 BST	7.5 GMT 2.5 BST
Evening period	fridge/freezer television washing machine for 1hr	8.5	

The figures for sensible and latent heat gains from cooking appliances and the cooking process, are shown below. Those from equipment are shown overleaf.

Appliance	Rate of heat release when in use, in Watts Sensible	Latent
Electric oven	830	170
Electric ring	830	170
Gas oven	1,360	340
Gas ring	1,360	340

	Operating period in hours	Usage
Oven	3	2.5 times / week at various times
Ring	0.5	3 times / day early morning, lunchtime, early evening

The BAeSEMA report points out that energy use for cooking has declined in recent years and is likely to fall further. The energy efficiency of cookers is increasing, particularly in the case of gas cookers. 44% of households owned a microwave cooker in 1988 and ownership is projected to rise to 70% by the year 2,000.

Equipment gains

Appliance	Rate of heat release when in use, in Watts Sensible	Latent
Fridge Average of models in use Average of new UK models Best new UK model Best world model (usage; continuous)	 40.0 34.5 18.3 10.3	
Fridge / freezer Average of models in use Average of new UK models Best new UK model (usage; continuous)	 83.0 63.1 32.0	
Freezer Average of models in use Average of new UK models Best new UK model Best world model (usage; continuous)	 85.0 61.8 27.4 20.6	
Electric kettle Total output when in use 770 Watts, minus 30% for heat lost via drains = 539 Watts, of which 30% latent (usage; 15mins, 4 times/day)	377.0	162.0
Washing machine Total output when in use, 700 Watts minus 55% for heat loss via drains (usage; 1.2 hours/wash, 5 washes/week)	315.0	
Dishwasher Total output when in use, 1190 Watts minus 60% for heat loss via drains (usage; 1.2 hours/wash, 1 wash/day)	476.0	
Tumble drier Total output when in use, 750 Watts for 1.5 hours/load, 5 loads/week Minus 80% for heat lost through exhaust	150.0	
Television (usage; 5 hours/day)	110.0	

Useful sensible heat gain from other appliances, 44 Watts during waking hours.

Heat gains from water heating

The work conducted for the Building Research Establishment [BAeSEMA Ltd,1992], gives a range of formulae for assessing the heat gains to be expected from a range of water heating systems. The following two systems have been selected for use in this study;

System 3: low thermal mass conventional gas boiler, cylinder thermostat, lagged primary circuit and conventionally lagged cylinder.
Mean rate of useful heat gain = 103+26 x N Watts
Substituting a condensing boiler would reduce gains by 3%
where N= the number of people in the household

This system was used for the Greenwich Meantime period giving as an average figure;

Mean rate of useful heat gain = 6.0 Watts/m^2 of total floor area of zone 4

System 4: immersion heater with conventionally lagged cylinder
Mean rate of useful heat gain = 90+17 x N Watts
where N= the number of people in the household
This system was used for the British Summertime period giving as an average figure;

Mean rate of useful heat gain = 4.5 Watts/m^2 of total floor area of zone 4

The water heating system was changed for the Summertime on the basis of the following findings
"Many households have more than one type of system (for water heating) and the balance of use varies seasonally. Nearly 60% of households use their central heating boiler in winter, but this drops to under 50% in Summer. Conversely the use of electric immersion and instantaneous heaters increases from 25% in winter to nearly 40% in summer. " [DOE 1 * 1986]CHECK

Infiltration Rates

The values for air change rates due to infiltration given below were adopted for this study. The figure for the glazed space was taken from the Passys II report [Baker et al, 1991]. The figures for the house were based on information from BS 5250: 1989 Control of Condensation in Buildings and work conducted for the Building Research Establishment [BAeSEMA Ltd,1992], taking into account the increased awareness within the volume house building industry of the benefits of improvements in construction techniques, such as draught stripping of door and window openings. These items have also been included in the requirements of the revised Building Regulations, Part L [1995].

	Air changes/hour
Glazed space - doors and windows closed	0.85
House - external doors and windows closed	0.75
House - intermittent use of windows and external doors	1.0

The infiltration rate of 1ac/h was used for the living areas for certain periods, to represent times when occupants would be entering and leaving, such as between 7.00hrs and 9.00hrs and between 17.00hrs and 19.00hrs. It was also used in the ancillary areas to represent open windows and the use of extract fans.

Increased values for the air change rates in the glazed space were introduced to specific simulations in order to test the effect of increasing air infiltration in reducing overheating. These are specified in the text.

BS 5250: 1989 Control of Condensation in Buildings, gives the following data for typical ventilation (infiltration rates for dwellings) in its' Appendix B, Table 4 Typical ventilation rates in air changes per hour, as shown below;

Resistance of construction to air leakage	Sheltered site	Exposed site
Well sealed	0.5	1.0
Average	1.0	1.5
Leaky	1.5	2.0

Space Heating

The heating schedules for the house, shown below, involve morning and evening heating periods on weekdays, and all day heating at weekends, and were based on the findings included in the work conducted for the Building Research Establishment. [BAeSEMA Ltd, 1992], discussed below.

	Greenwich Mean Time		British Summertime -Time entered as corresponding GMT	
	Weekday	Weekend	Weekday	Weekend
ON	06.00hrs	06.00hrs	05.00hrs	05.00hrs
OFF	09.00hrs	23.00hrs	08.00hrs	22.00hrs
ON	16.00hrs	----------	15.00hrs	----------
OFF	23.00hrs	----------	22.00hrs	----------

Note: 'ON' times reflect the one hour needed to bring the temperature up to the set point.

Extracts from the BAeSEMA Ltd research on which the schedules are based are as follows:

Chapter 3;3.1 Energy use and occupant behaviour in the UK,"Less than 40% of homes are heated all day on weekdays; it is more common to heat for a short period each morning, and throughout the evening. All day heating predominates at weekends. This pattern is observed even in low energy homes and seems likely to persist."

Chapter 4;4.2.1 Heating; 4.2.1.2 Recommended approach,"- in dynamic models, to use case-specific set-points and heating schedules where possible. Three suggested scenarios, corresponding to the three most common patterns of heating observed in field trials, are as follows"

Strategy	Heating schedule
All day	7am -11pm
Morning and evening	7-9am ; 5 -11pm
Evening	5 -11pm

Heating set-point air temperatures, chosen for this study, for the different areas of accommodation are set out below

Accommodation	Set-point air temperature
Glazed space, where heated	20°C
Living areas	20°C
Bedrooms	18°C
Ancillary spaces	18°C

Figures for the living areas, bedrooms and ancillary spaces are taken from several sources.

In work conducted for the Building Research Establishment [BAeSEMA Ltd,1992] Chapter 6, Individual component dataset; Heating, recommends, "the use of the following set point temperatures, typical of observations in modern homes and based on field trials:"

Living room	20°C
Rest of house	18°C

M A Humphreys, in his article, "Desirable temperatures in dwellings" [Building Services Engineer, 1976] suggests normal settings of around 21°C for living rooms, 17°C for kitchens, 15°C for circulation areas and 15-22°C for bedrooms, depending on use.
The CIBSE Guide [CIBSE,1986] recommends a temperature of 20°C for dining rooms.
In terms of the Living room set-point, in the models under test for this study, the kitchen and dining room are included in the Living rooms zone and therefore the temperature of 20°C seems to be an appropriate set point temperature.

The figure for the glazed space set point temperature of 20°C is based on the use of the space as a living room.

The figure for the glazed space set point temperature of 20°C is based on the use of the space as a living room and on the results of the Market Research into the Use of Conservatories. [Moon,1991] [Oreszczyn,[1]1993]
Out of 388 responses, 188 fell into the three largest groups as follows:
61 .. 18°C) }
60 .. 20°C) } average=19.7°C
66 .. 21°C) }

APPENDIX E

Building Constructions Data-sheets

- Single glazing
- Double glazing
- Low E glazing
- Single glazing with insulating blind
- Double glazing with insulating blind
- Low E glazing with insulating blind
- Double glazing with internal medium blind
- Double glazing with external medium blind
- Floor of glazed space with carpet finish
- Floor of glazed space with clay tile finish
- External wall
- Insulated ceiling [roof / floor]
- Insulated roof
- Ceiling / upper floor
- Ground floor
- Internal wall

Time Now	Date	Consultant	Program
14:42:39	19:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bssg/ 1

C-Code: bssg/1

Construction name: single glazing U=5.37

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [No]

Solar Transmittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Transmittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.780	0.075	0.075	0.075	0.075	0.870	0.845	0.845	166.667

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	amlpilk/2 6MM CLEAR FLOAT	6.00	0.780	0.070	0.070	0.845	0.845	1.000	-	99999.000
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 5.445 (Wall) 6.386 (Roof)

Time Now	Date	Consultant	Program
14:41:37	19:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsdg/ 1

C-Code: bsdg/1

Construction name: 4/12/4 U=2.78

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [No]

Solar Trans-mittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Trans-mittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.676	0.116	0.091	0.116	0.091	0.797	0.845	0.845	5.580

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1pilk/1	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
	4MM CLEAR FLOAT									
2	am1cav/2	12.00	-	-	-	-	-	-	2.080	1.000
	12MM AIR (HORIZONTAL FLOW)									
3	am1pilk/1	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
	4MM CLEAR FLOAT									
4										
5										
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 2.802 (Wall) 3.032 (Roof)

Time Now	Date	Consultant	Program
14:43:49	19:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsdg/ 2

C-Code: bsdg/2

Construction name: 4lowE/12/4 U=1.78

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [No]

Solar Transmittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Transmittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.549	0.128	0.116	0.186	0.074	0.768	0.845	0.845	2.627

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1pilk/25	4.00	0.660	0.200	0.160	0.120	0.845	1.000	-	99999.000
	4MM KAPPAFLOAT (NEUTRAL)									
2	am1cav/2	12.00	-	-	-	-	-	-	2.080	1.000
	12MM AIR (HORIZONTAL FLOW)									
3	am1pilk/1	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
	4MM CLEAR FLOAT									
4										
5										
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 1.791 (Wall) 1.882 (Roof)

Time Now	Date	Consultant	Program
14:37:27	13:Oct:95	ACADEMIC USE	A-Tas 7.96

DATABASE CONSTRUCTION

C-Code: bssgb/2

Construction name: insulating blind single glaz U=2.04

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [Yes]

Solar Trans-mittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Trans-mittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.000	0.310	0.558	0.709	0.191	0.000	0.845	0.400	2.330

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	bsblind/1 insulating blind	6.00	0.000	0.100	0.100	0.400	0.400	0.033	-	9999.000
2	am1cav/3 15MM AIR (HORIZONTAL FLOW)	15.00	-	-	-	-	-	-	1.670	1.000
3	am1pilk/2 6MM CLEAR FLOAT	6.00	0.780	0.070	0.070	0.845	0.845	1.000	-	99999.000
4										
5										
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 2.061 (Wall) 2.107 (Roof)

Time Now	Date	Consultant	Program
14:45:55	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsdgb/ 1

C-Code: bsdgb/1

Construction name: insulating blind/4/12/4 U=1.510

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [Yes]

Solar Transmittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Transmittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.000	0.285	0.552	0.764	0.136	0.000	0.845	0.400	1.660

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	bsblind/1 insulating blind	6.00	0.000	0.100	0.100	0.400	0.400	0.033	-	9999.000
2	amlcav/3 15MM AIR (HORIZONTAL FLOW)	15.00	-	-	-	-	-	-	1.670	1.000
3	amlpilk/1 4MM CLEAR FLOAT	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
4	amlcav/2 12MM AIR (HORIZONTAL FLOW)	12.00	-	-	-	-	-	-	2.080	1.000
5	amlpilk/1 4MM CLEAR FLOAT	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 1.519 (Wall) 1.543 (Roof)

Time Now	Date	Consultant	Program
14:46:38	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsdgb/ 2

C-Code: bsdgb/2

Construction name: insulating blind 4lowE/12/4 U=1.158

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [Yes]

Solar Trans-mittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Trans-mittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.000	0.256	0.507	0.798	0.102	0.000	0.845	0.400	1.244

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	bsblind/1 insulating blind	6.00	0.000	0.100	0.100	0.400	0.400	0.033	-	9999.000
2	am1cav/3 15MM AIR (HORIZONTAL FLOW)	15.00	-	-	-	-	-	-	1.670	1.000
3	am1pilk/25 4MM KAPPAFLOAT (NEUTRAL)	4.00	0.660	0.200	0.160	0.120	0.845	1.000	-	99999.000
4	am1cav/2 12MM AIR (HORIZONTAL FLOW)	12.00	-	-	-	-	-	-	2.080	1.000
5	am1pilk/1 4MM CLEAR FLOAT	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 1.163 (Wall) 1.177 (Roof)

Time Now	Date	Consultant	Program
15:24:38	22:Mar:96	ACADEMIC USE	A-Tas 7.96

DATABASE CONSTRUCTION

C-Code: bsdgib/2

Construction name: internal medium blind 4/12/4

TRANSPARENT CONSTRUCTION External Blind? [No] Internal Blind? [Yes]

Solar Trans-mittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Trans-mittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.050	0.206	0.435	0.539	0.011	0.059	0.845	0.845	2.667

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1blind/2 MEDIUM BLIND	1.00	0.070	0.400	0.400	0.845	0.845	999.000	-	99999.000
2	am1cav/5 50MM AIR (HORIZONTAL FLOW)	50.00	-	-	-	-	-	-	1.010	1.000
3	am1pilk/1 4MM CLEAR FLOAT	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
4	am1cav/2 12MM AIR (HORIZONTAL FLOW)	12.00	-	-	-	-	-	-	2.080	1.000
5	am1pilk/1 4MM CLEAR FLOAT	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 2.321 (Wall) 2.378 (Roof)

Time Now	Date	Consultant	Program
15:25:40	22:Mar:96	ACADEMIC USE	A-Tas 7.96

DATABASE CONSTRUCTION

C-Code: bsdgeb/2

Construction name: 4/12/4 medium blind

TRANSPARENT CONSTRUCTION External Blind? [Yes] Internal Blind? [No]

Solar Trans-mittance	External Solar Absorptance (ext. surf.)	(int. surf.)	Internal Solar Absorptance (int. surf.)	(ext. surf.)	Light Trans-mittance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.050	0.012	0.007	0.153	0.488	0.059	0.845	0.845	5.055

Layer Number	M-Code & Material Name	Width (mm)	Solar Tran.	Ext. Solar Refl.	Int. Solar Refl.	Int. Emis.	Ext. Emis.	Conductivity (W/m C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1pilk/1	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
	4MM CLEAR FLOAT									
2	am1cav/2	12.00	-	-	-	-	-	-	2.080	1.000
	12MM AIR (HORIZONTAL FLOW)									
3	am1pilk/1	4.00	0.820	0.070	0.070	0.845	0.845	1.000	-	99999.000
	4MM CLEAR FLOAT									
4	am1cav/5	50.00	-	-	-	-	-	-	1.010	1.000
	50MM AIR (HORIZONTAL FLOW)									
5	am1blind/2	1.00	0.070	0.400	0.400	0.845	0.845	999.000	-	99999.000
	MEDIUM BLIND									
6										
7										
8										
9										
10										
11										
12										

U VALUES (W/m2K): 2.663 (Wall) 2.870 (Roof)

Time Now	Date	Consultant	Program
14:30:42	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsgsf/ 1

C-Code: bsgsf/1	Construction name: glazed space floor-carpet on screed

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.820	0.700	0.910	0.900	0.303	502.8

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1fin/3 CARPET *2	5.00	0.060	186.0	1360.0	-	2.000
2	am1concd/9 CONCRETE SCREED *3	50.00	1.280	2100.0	1000.0	-	34.000
3	am1concd/2 CONCRETE 3% m.c. 9 *3	100.00	1.130	2000.0	920.0	-	34.000
4	am1aggr/36 NO FINES STOCK BRICK 1:6 *2	150.00	0.650	1570.0	1057.0	-	14.800
5	am1soil/1 CLAY 1 (DARK) *2	2000.00	0.700	1280.0	1840.0	-	99999.000
6							
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.288 (Wall) 0.290 (Roof) 0.283 (Internal) 0.291 (Ground Floor)

Time Now	Date	Consultant	Program
15:26:13	22:Mar:96	ACADEMIC USE	A-Tas 7.96

DATABASE CONSTRUCTION

C-Code: bsgsf/2

Construction name: glazed space floor - clay tile

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.820	0.700	0.910	0.900	0.312	476.2

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1tile/2 CLAY,RED/BROWN *4	10.00	0.850	1900.0	837.0	-	52.000
2	am1concd/9 CONCRETE SCREED *3	25.00	1.280	2100.0	1000.0	-	34.000
3	am1concd/2 CONCRETE 3% m.c. 9 *3	100.00	1.130	2000.0	920.0	-	34.000
4	am1aggr/36 NO FINES STOCK BRICK 1:6 *2	150.00	0.650	1570.0	1057.0	-	14.800
5	am1soil/1 CLAY 1 (DARK) *2	2000.00	0.700	1280.0	1840.0	-	99999.000
6							
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.296 (Wall) 0.298 (Roof) 0.291 (Internal) 0.299 (Ground Floor)

Time Now	Date	Consultant	Program
14:18:05	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsews/ > 0

C-Code: bsews/1

Construction name: external wall slow response U=0.43

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.725	0.400	0.930	0.850	0.465	4.7

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/8 LIGHTWEIGHT PLASTER 8 *3	13.00	0.201	770.0	837.0	-	11.000
3	am1block/4 CLINKER CONCRETE BLOCK *1	100.00	0.350	1050.0	1057.0	-	14.800
4	am1ins/2 GLASS FIBRE 2 *3	50.00	0.035	25.0	1000.0	-	2.880
5	am1cav/4 20MM AIR (HORIZONTAL FLOW)	20.00	-	-	-	1.270	1.000
6	am1brick/4 BRICKWORK 1% m.c. *4	105.00	0.540	1600.0	750.0	-	8.000
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.430 (Wall) 0.435 (Roof) 0.419 (Internal) 0.435 (Ground Floor)

Time Now	Date	Consultant	Program
14:39:52	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsrf/ 1

C-Code: bsrf/1

Construction name: roof/floor U=0.245

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.600	0.400	0.900	0.850	0.255	0.0

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/20 PLASTERBOARD *4	13.00	0.160	960.0	837.0	-	11.000
3	am1ins/3 GLASSWOOL 1 *2	150.00	0.039	24.0	920.0	-	1.500
4							
5							
6							
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.244 (Wall) 0.245 (Roof) 0.240 (Internal) 0.245 (Ground Floor)

Time Now	Date	Consultant	Program
14:44:10	01:Sep:95	ACADEMIC USE	A-Tcs 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsir/ 1

C-Code: bsir/1	Construction name: insulated roof

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.700	0.400	0.900	0.850	0.348	0.0

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/20 PLASTERBOARD *4	13.00	0.160	960.0	837.0	-	11.000
3	am1ins/3 GLASSWOOL 1 *2	100.00	0.039	24.0	920.0	-	1.500
4	am1cav/13 50MM AIR (UPWARD FLOW)	50.00	-	-	-	1.770	1.000
5	am1asph/9 ROOFING FELT 1 *2	5.00	0.410	960.0	1000.0	-	1300.000
6	am1tile/2 CLAY,RED/BROWN *4	40.00	0.850	1900.0	837.0	-	52.000
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.328 (Wall) 0.331 (Roof) 0.322 (Internal) 0.331 (Ground Floor)

Time Now	Date	Consultant	Program
14:44:58	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bscf/ 1

C-Code: bscf/1	Construction name: ceiling/upperfloor

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)
0.700	0.400	0.900	0.850	1.632

Time constant (hours)
0.7

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/20 PLASTERBOARD *4	20.00	0.160	960.0	837.0	-	11.000
3	am1cav/16 200MM AIR (UPWARD FLOW)	200.00	-	-	-	1.300	1.000
4	am1sheet/30 CHIP BOARD 2 *4	19.00	0.110	700.0	1570.0	-	96.000
5	am1fin/1 CELLULAR RUBBER UNDERLAY *2	5.00	0.100	400.0	1360.0	-	2.300
6	am1fin/3 CARPET *2	5.00	0.060	186.0	1360.0	-	2.000
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 1.267 (Wall) 1.312 (Roof) 1.175 (Internal) 1.314 (Ground Floor)

Time Now	Date	Consultant	Program
14:21:47	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsgf/ 1

C-Code: bsgf/1	Construction name: gr.fl. carpet on chipboard

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.820	0.700	0.910	0.900	0.214	844.8

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1fin/3 CARPET *2	5.00	0.060	186.0	1360.0	-	2.000
2	am1fin/1 CELLULAR RUBBER UNDERLAY *2	5.00	0.100	400.0	1360.0	-	2.300
3	am1sheet/17 PARTICLE BOARD MEDIUM DENSITY *3	20.00	0.135	800.0	1300.0	-	3.840
4	am1ins/12 POLYSTRENE EXPANDED SHEET CLOSED CELL *2	40.00	0.033	32.0	1210.0	-	74.000
5	am1concd/2 CONCRETE 3% m.c. 9 *3	100.00	1.130	2000.0	920.0	-	34.000
6	am1aggr/36 NO FINES STOCK BRICK 1:6 *2	150.00	0.650	1570.0	1057.0	-	14.800
7	am1soil/1 CLAY 1 (DARK) *2	2000.00	0.700	1280.0	1840.0	-	99999.000
8							
9							
10							
11							
12							

U VALUES (W/m2K): 0.207 (Wall) 0.208 (Roof) 0.204 (Internal) 0.208 (Ground Floor)

Time Now	Date	Consultant	Program
14:48:25	01:Sep:95	ACADEMIC USE	A-Tas 7.96

CONSTRUCTIONS DATABASE

Search Pattern: bsiws/ > 0

C-Code: bsiws/1	Construction name: internal wall slow response

OPAQUE CONSTRUCTION

External Solar Absorptance	Internal Solar Absorptance	External Emissivity	Internal Emissivity	Conductance (W/m2 C)	Time constant (hours)
0.400	0.400	0.850	0.850	3.378	2.8

Layer Number	M-Code & Material Name	Width (mm)	Conductivity (W/m C)	Density (kg/m3)	Specific Heat (J/kg C)	Convection Coefficient (W/m2 C)	Vapour Diffusion Factor
Inside	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
2	am1plast/8 LIGHTWEIGHT PLASTER 8 *3	13.00	0.201	770.0	837.0	-	11.000
3	am1block/3 FOAMED SLAG CONCRETE BLOCK *1	100.00	0.600	2000.0	1050.0	-	34.000
4	am1plast/8 LIGHTWEIGHT PLASTER 8 *3	13.00	0.201	770.0	837.0	-	11.000
5	am1s/39 WHITE, FLAT *1	1.00	999.999	0.0	0.0	-	5.565
6							
7							
8							
9							
10							
11							
12							

U VALUES (W/m2K): 2.114 (Wall) 2.241 (Roof) 1.857 (Internal) 2.251 (Ground Floor)

APPENDIX F

The Treatment of Direct and Diffuse Solar Radiation Incident on Surfaces in the Tas Thermal Analysis Simulations

- extracts from the Building Analysis (A-Tas) Theory Manual [Environmental Design Solutions Ltd]

Weatherfile Information

- Tas climate regions
- South-east and North-west weatherfiles: analysis of ambient temperature in hours per month, 8.00-23.00hrs.
- Monthly mean, minimum and maximum air temperatures in the South-east and North-west weatherfiles
- South-east weatherfile: maximum and minimum air temperatures in July
- South-east weatherfile: day 201
- South-east weatherfile: day 180
- South-east weatherfile: day 184
- South-east weatherfile: day 359

The Treatment of Direct and Diffuse Solar Radiation Incident on Surfaces in the Tas Thermal Analysis Simulations; extracts from the Building Analysis (A-Tas) Theory Manual [Environmental Design Solutions Ltd]

8. Solar Radiation

8.1 Solar Radiation Incident on the Building Exterior

Direct and Diffuse Solar Radiation

The Tas weather file provides hourly values for global (I_{hor}^{glob}) and diffuse (I_{hor}^{dif}) solar radiation measured on the horizontal (in W/m²). The direct radiation on the horizontal (I_{hor}^{dir}) is the difference between these quantities:

$$I_{hor}^{dir} = I_{hor}^{glob} - I_{hor}^{dif} \qquad (8-1)$$

To calculate the direct normal (beam) radiation intensity, a knowledge of sun position is required. This is calculated at hourly intervals using the Astronomical Almanac's algorithm[1]. Sun position is derived in the form of a unit vector pointing towards the sun:

$$\mathbf{u} = (u_1, u_2, u_3) \qquad (8-2)$$

The direct normal (beam) solar intensity is then obtained as

$$I^{beam} = I_{hor}^{dir} / u_3 \qquad (8-3)$$

From this the solar beam vector can then be calculated:

$$\mathbf{I}^{beam} = -I^{beam}\,\mathbf{u} \qquad (8-4)$$

This vector points in the direction of the solar beam and its magnitude is the direct normal solar radiation flux.

Direct Solar Radiation Incident on a Surface

The direct solar radiation incident on a surface, $\mathcal{J}^{dir}$ (Watts), is calculated as minus the inner product of the direct beam solar vector with the outward-pointing area vector of the surface (A_i), negative values being replaced by zero:

$$\mathcal{J}^{dir} = p(-\mathbf{I}^{beam} . A_i) \qquad (8-5)$$

where

$$p(x) = \begin{cases} x & (x > 0) \\ 0 & (x <= 0) \end{cases} \qquad (8-6)$$

The magnitude of the surface area vector A_i is taken to be the *component surface area* (A_i) which is the mean of the internal and external surface areas provided by 3D-Tas.

In appropriate cases the direct incident radiation is reduced by a shading factor read from a shading file or by calculations of the effects 'shading features' (overhangs, side-fins or recesses). These shading calculations may be applied to both transparent and opaque elements. For transparent elements the cosine of the angle of incidence is also obtained from the inner product and used in the calculation of transmission and absorption in the element.

Diffuse & Ground-Reflected Solar Radiation Incident on a Surface

The diffuse component of sky radiation is assumed to be isotropically distributed over solid angle. The diffuse solar radiant power incident on a surface from the sky, $\mathcal{J}^{sky}$ (Watts), is consequently the following function of the surface tilt:

$$\mathcal{J}^{sky} = A_i I_{hor}^{dif} \cos^2(\gamma/2) \qquad (8-7)$$

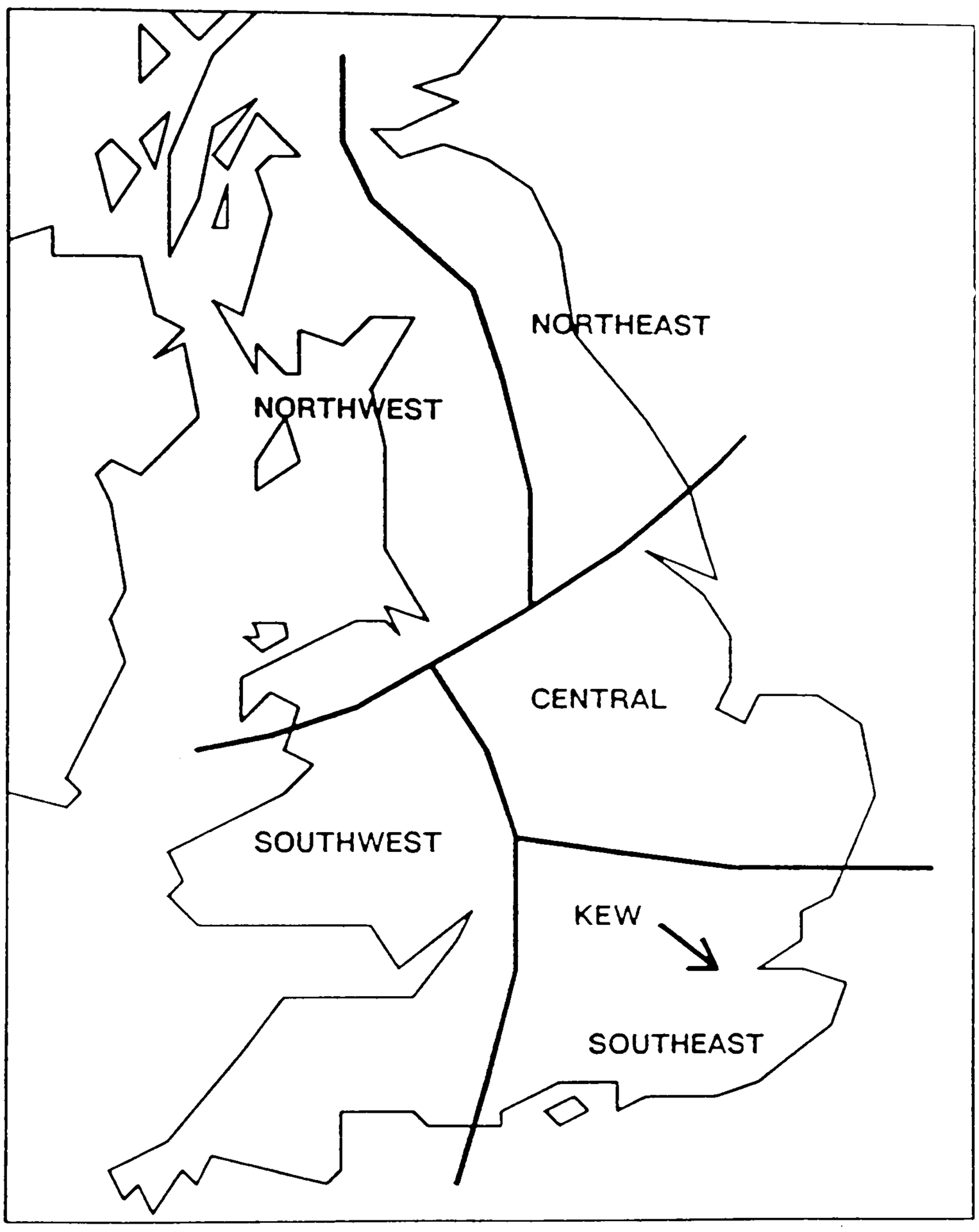
where γ is the tilt angle from the horizontal.

The ground-reflected radiation is also assumed to be isotropic. The incident ground-reflected radiation, $\mathcal{J}^{gnd}$, is the product of the component area (A_i), the global radiation incident radiation on the horizontal plane, the ground reflectance ρ^{gnd} (which the user may set), and an angle factor arising from integration over solid angle:

$$\mathcal{J}^{gnd} = A_i\ \rho^{gnd}\ I_{hor}^{glob} \sin^2(\gamma/2) \qquad (8-8)$$

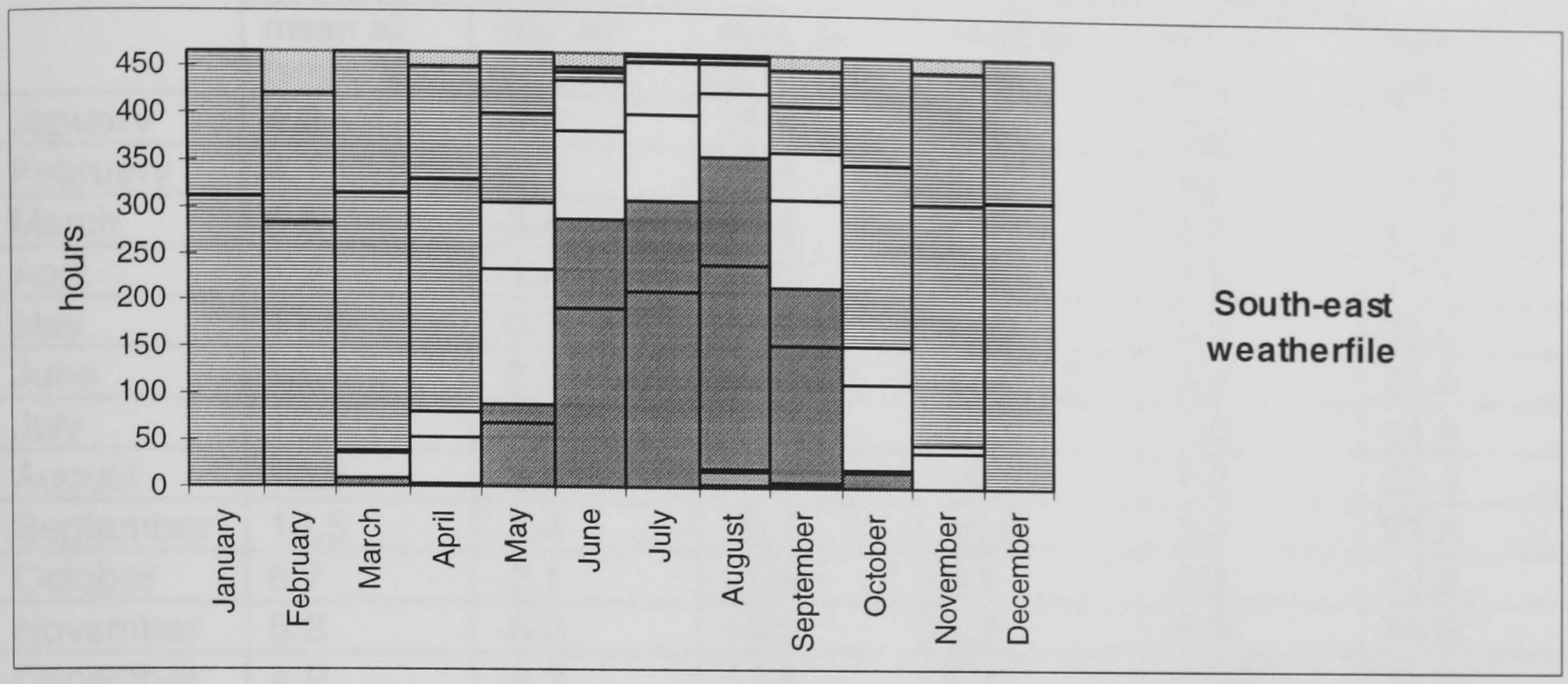
Tas does not account for diffuse radiation shading.

Tas climate regions



UK Climate Regions
(Climatic Research Unit, University of East Anglia)

Southeast weatherfile: analysis of air temperature in hours / month, 8.00-23.00hrs



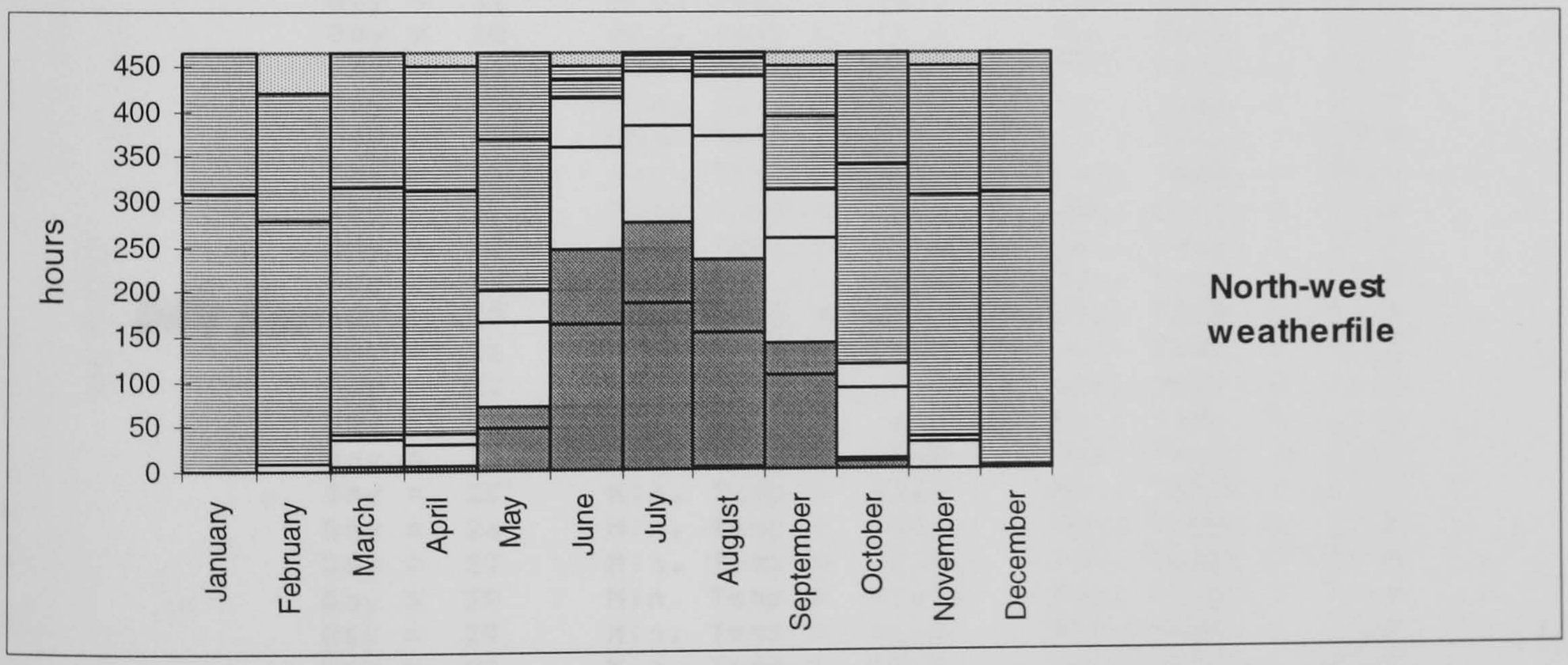
air temperature below 12°C
evening
morning and afternoon

air temperature 12°C -15°C
evening
morning and afternoon

air temperature 16°C - 27°C
evening
morning and afternoon

air temperature above 27°C
evening
morning and afternoon

Northwest weatherfile: analysis of air temperature in hours / month, 8.00-23.00hrs



air temperature below 12°C
evening
morning and afternoon

air temperature 12°C -15°C
evening
morning and afternoon

air temperature 16°C - 27°C
evening
morning and afternoon

air temperature above 27°C
evening
morning and afternoon

Monthly mean, minimum and maximum air temperatures in the South-east and North-west weatherfiles

	south-east weatherfile			north-west weatherfile		
	mean air temp. °C	min. air temp. °C	max. air temp. °C	mean air temp. °C	min. air temp. °C	max. air temp. °C
January	4.2	-2.7	11.6	4.4	-6.0	11.8
February	4.1	-5.7	11.9	4.4	-13.3	13.5
March	5.5	-5.4	17.6	6.6	-2.5	17.9
April	7.2	-1.8	16.7	6.4	-3.5	17.1
May	11.5	0.0	22.4	10.8	0.3	23.0
June	15.1	2.2	27.2	15.0	2.4	24.6
July	15.7	4.2	25.8	15.4	7.0	24.9
August	16.8	5.8	30.3	15.1	7.5	27.4
September	14.5	3.4	29.1	13.0	3.7	23.8
October	8.7	-2.1	21.8	8.5	-0.6	18.2
November	5.3	-8.0	15.7	5.2	-8.5	14.8
December	4.9	-8.3	11.8	4.4	-10.9	12.8

South-east weatherfile: maximum and minimum air temperatures in July

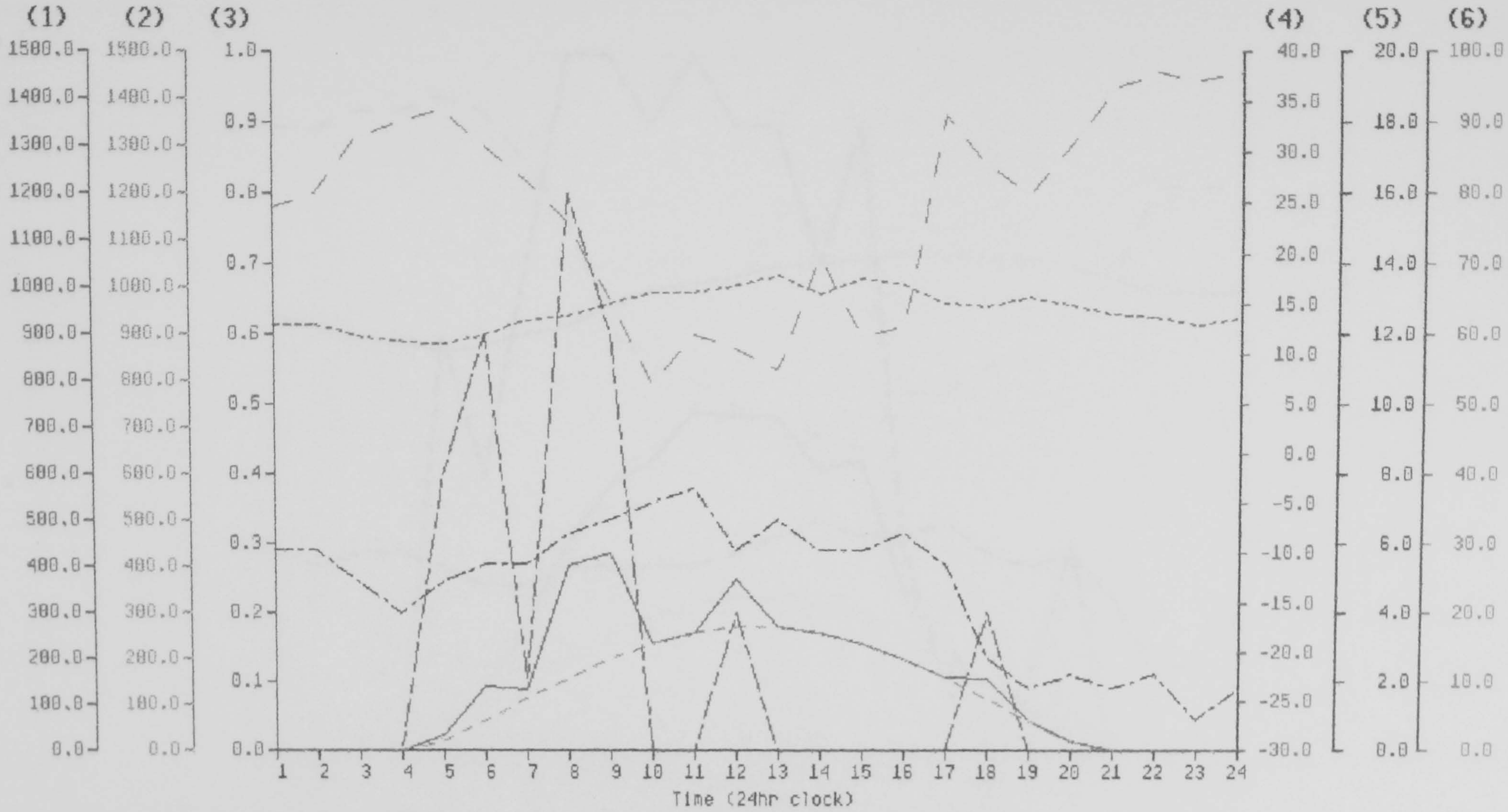
Month = 7 (July)

Day = 1	Min. Temp = 11.3	Max. Temp. = 25.8
Day = 2	Min. Temp = 14.2	Max. Temp. = 22.6
Day = 3	Min. Temp = 11.0	Max. Temp. = 23.6
Day = 4	Min. Temp = 10.7	Max. Temp. = 23.6
Day = 5	Min. Temp = 9.3	Max. Temp. = 24.8
Day = 6	Min. Temp = 14.9	Max. Temp. = 20.3
Day = 7	Min. Temp = 10.2	Max. Temp. = 17.3
Day = 8	Min. Temp = 7.0	Max. Temp. = 19.6
Day = 9	Min. Temp = 8.5	Max. Temp. = 21.4
Day = 10	Min. Temp = 11.5	Max. Temp. = 20.2
Day = 11	Min. Temp = 15.0	Max. Temp. = 19.6
Day = 12	Min. Temp = 14.6	Max. Temp. = 19.7
Day = 13	Min. Temp = 12.9	Max. Temp. = 22.3
Day = 14	Min. Temp = 12.1	Max. Temp. = 20.7
Day = 15	Min. Temp = 13.5	Max. Temp. = 20.0
Day = 16	Min. Temp = 12.4	Max. Temp. = 20.0
Day = 17	Min. Temp = 12.6	Max. Temp. = 19.2
Day = 18	Min. Temp = 9.0	Max. Temp. = 18.3
Day = 19	Min. Temp = 11.6	Max. Temp. = 19.8
DAY 201 Day = 20	Min. Temp = 11.0	Max. Temp. = 17.9
Day = 21	Min. Temp = 10.3	Max. Temp. = 19.2
Day = 22	Min. Temp = 7.6	Max. Temp. = 17.3
Day = 23	Min. Temp = 6.3	Max. Temp. = 14.9
Day = 24	Min. Temp = 4.2	Max. Temp. = 17.7
Day = 25	Min. Temp = 10.8	Max. Temp. = 19.2
Day = 26	Min. Temp = 11.1	Max. Temp. = 19.1
Day = 27	Min. Temp = 7.3	Max. Temp. = 19.4
Day = 28	Min. Temp = 11.9	Max. Temp. = 18.6
Day = 29	Min. Temp = 11.3	Max. Temp. = 18.7
Day = 30	Min. Temp = 13.4	Max. Temp. = 23.4
Day = 31	Min. Temp = 9.1	Max. Temp. = 24.2

Tas Weather Data
==========

File : uk_southeast.wfl
Latitude 51.50 deg north
G W Temp 11.50 deg C

Day 201
Jul 20



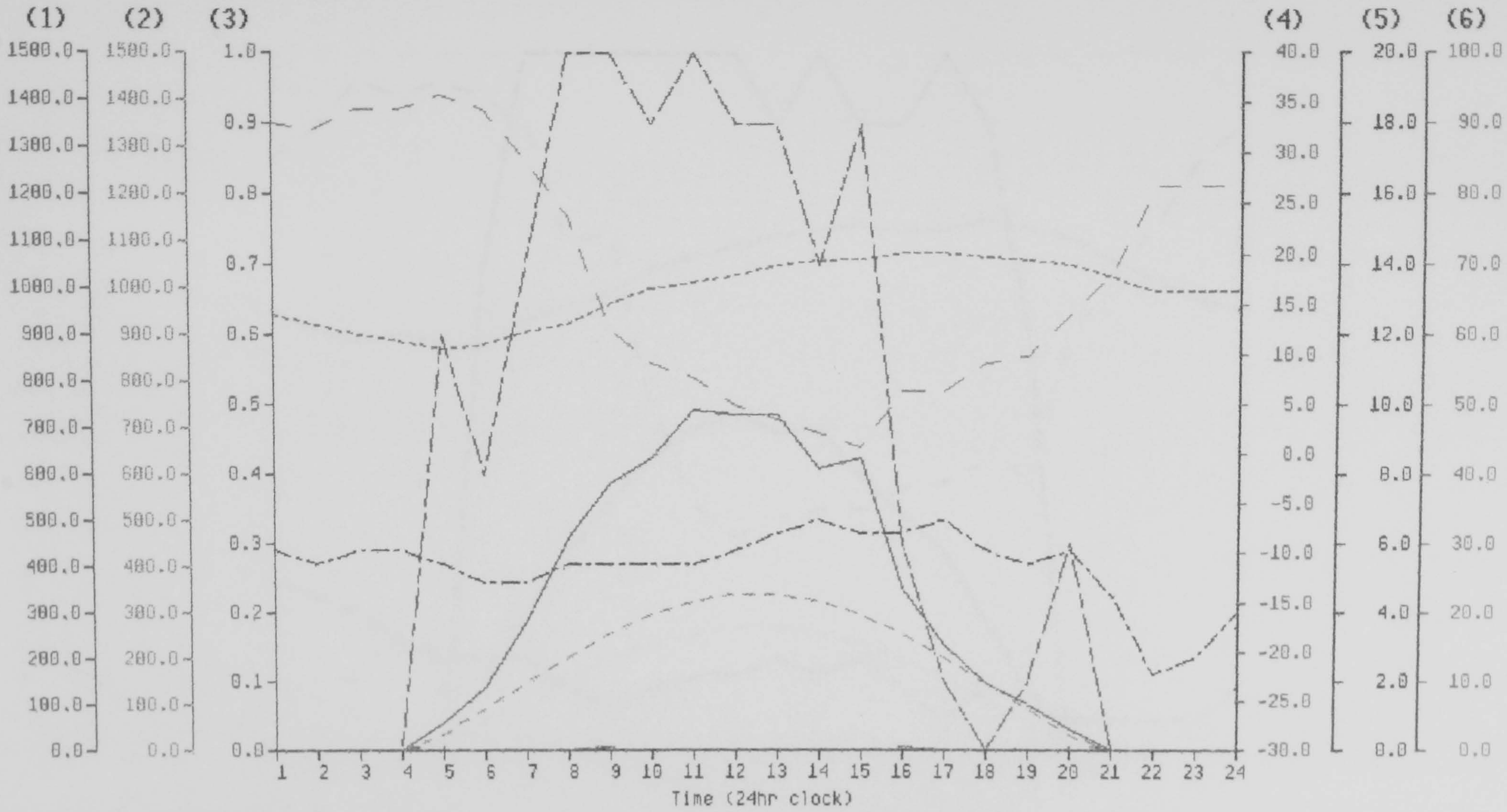
(1) GLOBAL Radiation (W/m2) ————————
(2) DIFFUSE Radiation (W/m2) - - - - - - - - - - -
(3) SUNSHINE Duration (hrs) ——————————
(4) DRY BULB Temp. (deg C) ----------
(5) WIND Speed (m/s) —·—·—·—·—·—
(6) HUMIDITY (%) — — — — — —

print
continue
exit

Tas Weather Data
==========

File : uk_southeast.wfl
Latitude 51.50 deg north
G W Temp 11.50 deg C

Day 180
Jun 29



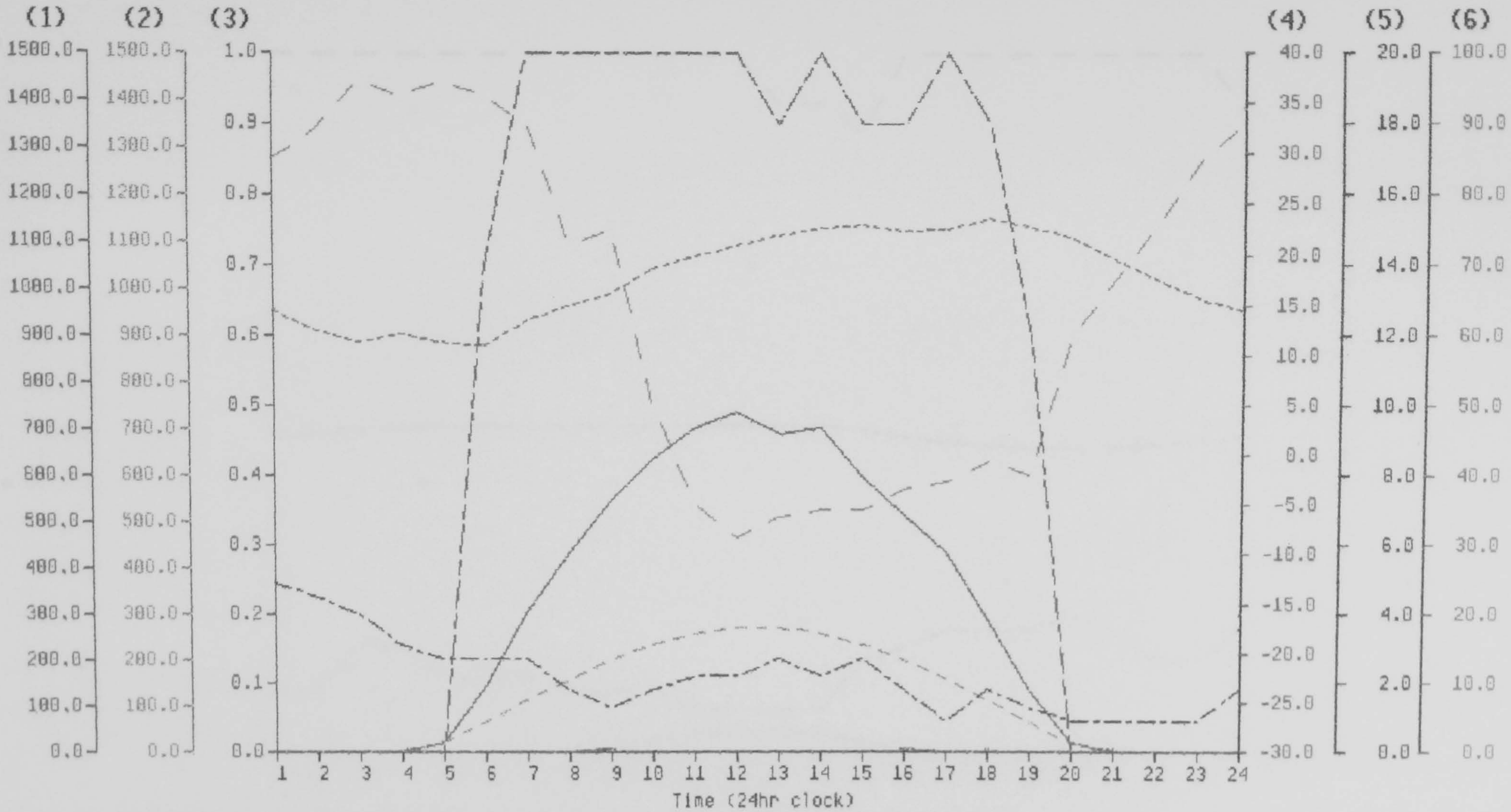
(1) GLOBAL Radiation (W/m2) ————————
(2) DIFFUSE Radiation (W/m2) - - - - - - - - - - -
(3) SUNSHINE Duration (hrs) — — — — — — — — —
(4) DRY BULB Temp. (deg C) ----------
(5) WIND Speed (m/s) —·—·—·—·—·—
(6) HUMIDITY (%) — — — — — —

print
continue
exit

Tas Weather Data
==========

File : uk_southeast.wfl
Latitude 51.50 deg north
G W Temp 11.50 deg C

Day 184
Jul 3



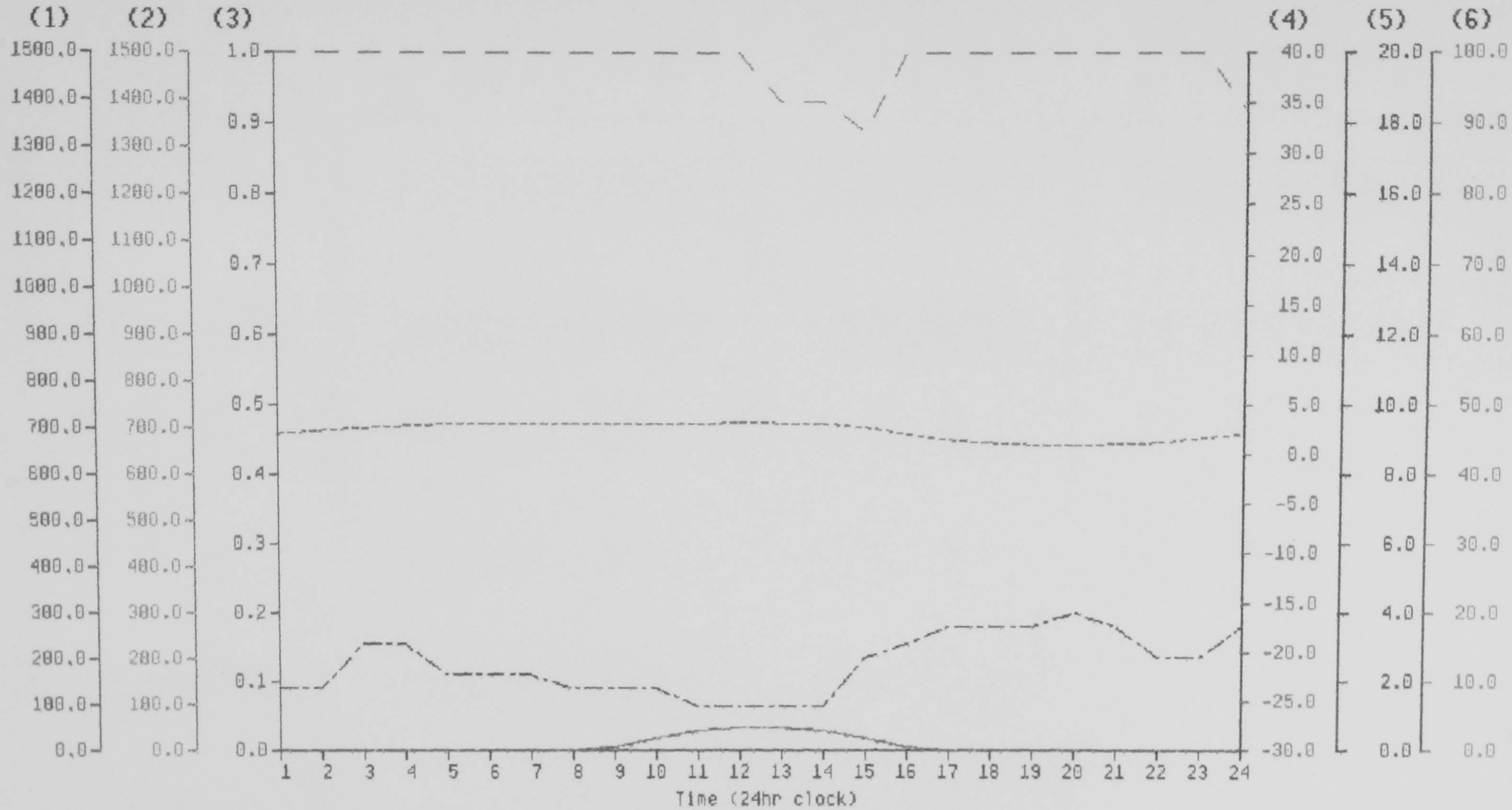
(1) GLOBAL Radiation (W/m2) ————————
(2) DIFFUSE Radiation (W/m2) - - - - - - - - - - -
(3) SUNSHINE Duration (hrs) — — — — — — — — —
(4) DRY BULB Temp. (deg C) ----------
(5) WIND Speed (m/s) —·—·—·—·—·—
(6) HUMIDITY (%) — — — — — —

print
continue
exit

Tas Weather Data
==========

File : uk_southeast.wfl
Latitude 51.50 deg north
G W Temp 11.50 deg C

Day 359
Dec 25



(1) GLOBAL Radiation (W/m2) ————————
(2) DIFFUSE Radiation (W/m2) - - - - - - - - - - -
(3) SUNSHINE Duration (hrs) ——————————
(4) DRY BULB Temp. (deg C) ----------
(5) WIND Speed (m/s) —·—·—·—·—·—
(6) HUMIDITY (%) — — — — — —

print
continue
exit

APPENDIX G

Results of the Thermal Simulations for the Single Storey Glazed Space

HEATING LOADS AND COSTS, 90M² HOUSES AND GLAZED SPACES

SOUTHEAST WEATHERFILE

90 north	house heating load		gl. sp. heating load			% decrease	% increase
	kWhs	£	kWhs	£	total cost	on basic	on basic
basic house	4370	£67			£67		
unheated single	4185	£64			£64	4.2%	
heated single	4047	£62	3541	£55	£117		73.6%
hs+insul. blind	4031	£62	3361	£52	£114		69.1%
unheated double	4131	£64			£64	5.5%	
heated double	3998	£62	2017	£31	£93		37.6%
hd+insul. blind	3938	£61	1385	£21	£82		21.8%
unheated lowE	4072	£63			£63	6.8%	
heated lowE	3951	£61	1253	£19	£80		19.1%
hlowE+insul blinc	3901	£60	927	£14	£74		10.5%
90 east	house heating load		gl. sp. heating load			% decrease	% increase
	kWhs	£	kWhs	£	total cost	on basic	on basic
basic house	4419	£68			£68		
unheated single	4242	£65			£65	3.9%	
heated single	4112	£63	3344	£51	£115		68.9%
unheated double	4181	£64			£64	5.3%	
heated double	4061	£63	1816	£28	£91		33.1%
unheated lowE	4118	£63			£63	6.7%	
heated lowE	4012	£62	1073	£17	£78		15.2%
90 south	house heating load		gl.sp.heating load			% decrease	% increase
	kWhs	£	kWhs	£	total cost	on basic	on basic
basic house	4062	£63			£63		
unheated single	3920	£60			£60	3.5%	
heated single	3803	£59	3027	£47	£105		68.2%
hs+insul. blind	3786	£58	2852	£44	£102		63.4%
unheated double	3852	£59			£59	5.2%	
heated double	3748	£58	1573	£24	£82		31.0%
hd+insul. blind	3663	£56	975	£15	£71		14.2%
unheated lowE	3804	£59			£59	6.3%	
heated lowE	3716	£57	899	£14	£71		13.6%
hlowE+insul blinc	3652	£56	613	£9	£66		5.0%
90 west	house heating load		gl.sp.heating load			% decrease	% increase
	kWhs	£	kWhs	£	total cost	on basic	on basic
basic house	4379	£67			£67		
unheated single	4206	£65			£65	4.0%	
heated single	4079	£63	3247	£50	£113		67.3%
unheated double	4145	£64			£64	5.3%	
heated double	4028	£62	1751	£27	£89		32.0%
unheated lowE	4083	£63			£63	6.8%	
heated lowE	3981	£61	1031	£16	£77		14.4%

HEATING COST = kWhs x £0.0154 **including VAT @ 8%**

HEATING LOADS AND COSTS, 90M² HOUSES AND GLAZED SPACES

NORTH-WEST WEATHERFILE

90 north	house heating load		gl sp heating load			%decrease	% increase
	kWhs	cost	kWhs	cost	total cost	on basic	on basic
basic house	4795	£74	0		£74		
unheated single	4605	£71	0		£71	4.0%	
heated single	4453	£69	3779	£58	£127		71.7%
unheated double	4550	£70	0		£70	5.1%	
heated double	4403	£68	2166	£33	£101		37.0%
unheated lowE	4488	£69	0		£69	6.4%	
heated lowE	4353	£67	1365	£21	£88		19.2%
90 east	house heating load		gl sp heating load			%decrease	% increase
	kWhs	cost	kWhs	cost	total cost	on basic	on basic
basic house	4817	£74	0		£74		
unheated single	4632	£71	0		£71	3.8%	
heated single	4487	£69	3626	£56	£125		68.4%
unheated double	4571	£70	0		£70	5.1%	
heated double	4434	£68	2019	£31	£99		34.0%
unheated lowE	4508	£69	0		£69	6.4%	
heated lowE	4385	£68	1240	£19	£87		16.8%
90 south	house heating load		gl sp heating load			%decrease	% increase
	kWhs	cost	kWhs	cost	total cost	on basic	on basic
basic house	4543	£70	0		£70		
unheated single	4385	£68	0		£68	3.5%	
heated single	4251	£65	3364	£52	£117		67.6%
unheated double	4317	£66	0		£66	5.0%	
heated double	4195	£65	1821	£28	£93		32.4%
unheated lowE	4264	£66	0		£66	6.1%	
heated lowE	4155	£64	1099	£17	£81		15.7%
90 west	house heating load		gl sp heating load			%decrease	% increase
	kWhs	cost	kWhs	cost	total cost	on basic	on basic
basic house	4777	£74			£74		
unheated single	4599	£71			£71	3.7%	
heated single	4457	£69	3525	£54	£123		67.1%
unheated double	4537	£70			£70	5.0%	
heated double	4404	£68	1954	£30	£98		33.1%
unheated lowE	4475	£69			£69	6.3%	
heated lowE	4355	£67	1196	£18	£85		16.2%

HEATING COST = kWhs x £0.0154 including VAT @ 8%

APPENDIX H

Results of the Thermal Simulations for the Two Storey Glazed Space

HEATING LOADS 110M^2 HOUSES AND GLAZED SPACES

SOUTHEAST WEATHERFILE

		INTEGRAL			SEMI-EXP'SED			EXPOSED	
110 north	house	gl.space	total	house	gl.space	total	house	gl.space	total
132 basic house	6632	0		6632	0		6632	0	
110 basic house	5308	0		5308	0		5308	0	
single unheated	5759	0	5759	5402	0	5402	5049	0	5049
single heated	5313	3357	8670	5072	5014	10086	4835	6698	11533
double unheated	5591	0	5591	5272	0	5272	4980	0	4980
double heated	5172	2312	7484	4952	3090	8042	4769	3756	8525
low E unheated	5441	0	5441	5149	0	5149	4905	0	4905
low E heated	5059	1621	6680	4851	2062	6913	4707	2391	7098
110 east	house	gl.space	total	house	gl.space	total	house	gl.space	total
	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs
132 basic house	6893	0		6893	0		6893	0	
110 basic house	5580	0		5580	0		5580	0	
single unheated	5955	0	5955	5688	0	5688	5358	0	5358
single heated	5560	2922	8482	5380	4589	9969	5151	6345	11496
double unheated	5761	0	5761	5529	0	5529	5275	0	5275
double heated	5403	1928	7331	5244	2684	7928	5079	3401	8480
low E unheated	5607	0	5607	5388	0	5388	5189	0	5189
low E heated	5286	1324	6610	5133	1717	6850	4965	2071	7036
110 south	house	gl.space	total	house	gl.space	total	house	gl.space	total
	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs
132 basic house	6381	0		6381	0		6381	0	
110 basic house	5178	0		5178	0		5178	0	
single unheated	5358	0	5358	5223	0	5223	5011	0	5011
single heated	5066	2175	7241	4965	3878	8843	4826	5726	10552
double unheated	5103	0	5103	5019	0	5019	4914	0	4914
double heated	4862	1288	6150	4799	2083	6882	4748	2907	7655
low E unheated	4937	0	4937	4875	0	4875	4844	0	4844
low E heated	4736	811	5547	4689	1254	5943	4700	1711	6411
110 west	house	gl.space	total	house	gl.space	total	house	gl.space	total
	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs	kWhs
132 basic house	6854	0		6854	0		6854	0	
110 basic house	5584	0		5584	0		5584	0	
single unheated	5923	0	5923	5676	0	5676	5367	0	5367
single heated	5549	2762	8311	5380	4410	9790	5166	6148	11314
double unheated	5718	0	5718	5510	0	5510	5282	0	5282
double heated	5381	1802	7183	5238	2547	7785	5093	3264	8357
low E unheated	5560	0	5560	5365	0	5365	5197	0	5197
low E heated	5260	1229	6489	5125	1616	6741	5029	1976	7005

COST OF HEATING 110M² HOUSES AND GLAZED SPACES — SOUTHEAST WEATHERFILE

		INTEGRAL			SEMI-EXPOSED			EXPOSED	
110 north	house	gl.space	total	house	gl.space	total	house	gl.space	total
132 basic house	£102			£102			£102		
110 basic house	£82			£82			£82		
single unheated	£89		£89	£83		£83	£78		£78
single heated	£82	£52	£134	£78	£77	£155	£74	£103	£178
double unheated	£86		£86	£81		£81	£77		£77
double heated	£80	£36	£115	£76	£48	£124	£73	£58	£131
low E unheated	£84		£84	£79		£79	£76		£76
low E heated	£78	£25	£103	£75	£32	£106	£72	£37	£109
110 east	house	gl.space	total	house	gl.space	total	house	gl.space	total
132 basic house	£106			£106			£106		
110 basic house	£86			£86			£86		
single unheated	£92		£92	£88		£88	£83		£83
single heated	£86	£45	£131	£83	£71	£154	£79	£98	£177
double unheated	£89		£89	£85		£85	£81		£81
double heated	£83	£30	£113	£81	£41	£122	£78	£52	£131
low E unheated	£86		£86	£83		£83	£80		£80
low E heated	£81	£20	£102	£79	£26	£105	£76	£32	£108
110 south	house	gl.space	total	house	gl.space	total	house	gl.space	total
132 basic house	£98			£98			£98		
110 basic house	£80			£80			£80		
single unheated	£83		£83	£80		£80	£77		£77
single heated	£78	£33	£112	£76	£60	£136	£74	£88	£163
double unheated	£79		£79	£77		£77	£76		£76
double heated	£75	£20	£95	£74	£32	£106	£73	£45	£118
low E unheated	£76		£76	£75		£75	£75		£75
low E heated	£73	£12	£85	£72	£19	£92	£72	£26	£99
110 west	house	gl.space	total	house	gl.space	total	house	gl.space	total
132 basic house	£106			£106			£106		
110 basic house	£86			£86			£86		
single unheated	£91		£91	£87		£87	£83		£83
single heated	£85	£43	£128	£83	£68	£151	£80	£95	£174
double unheated	£88		£88	£85		£85	£81		£81
double heated	£83	£28	£111	£81	£39	£120	£78	£50	£129
low E unheated	£86		£86	£83		£83	£80		£80
low E heated	£81	£19	£100	£79	£25	£104	£77	£30	£108

HEATING COST = kWhs x £0.0154 including VAT @ 8%

PERCENTAGE DECREASES AND INCREASES ON HEATING COSTS OF 132M^2 and 110m^2 HOUSE DUE TO INTEGRAL GLAZED SPACE					
	INTEGRAL				
110 north	total	% decrease	%increase	% decrease	%increase
		on132	on 132	on110	on 110
132 basic house	£102				
110 basic house	£82				
single unheated	£89				8.2%
single heated	£134		30.9%		
double unheated	£86				5.0%
double heated	£115		13.0%		
low E unheated	£84				2.2%
low E heated	£103		0.9%		
110 east	total	% decrease	%increase	% decrease	%increase
		on132	on 132	on110	on 110
132 basic house	£106				
110 basic house	£86				
single unheated	£92				6.6%
single heated	£131		23.2%		
double unheated	£89				3.2%
double heated	£113		6.5%		
low E unheated	£86				
low E heated	£102	4.0%			
110 south	total	% decrease	%increase	% decrease	%increase
		on132	on 132	on110	on 110
132 basic house	£98				
110 basic house	£80				
single unheated	£83				3.1%
single heated	£112		13.8%		
double unheated	£79				
double heated	£95	3.4%			
low E unheated	£76			0.50%	
low E heated	£85	12.8%			
110 west	total	% decrease	%increase	% decrease	%increase
		on132	on 132	on110	on 110
132 basic house	£106				
110 basic house	£86				
single unheated	£91				6.1%
single heated	£128		20.7%		
double unheated	£88				2.4%
double heated	£111		4.4%		
low E unheated	£86				
low E heated	£100	5.7%			

PERCENTAGE DECREASES AND INCREASES ON HEATING COSTS OF 110M² HOUSE DUE TO SEMI-EXPOSED AND EXPOSED SPACES S.E. WFL

	SEMI-EXPOSED			EXPOSED		
110 north	total	% decrease on 110	%increase on 110	total	% decrease on 110	%increase on 110
110 basic house	£82			£82		
single unheated	£83		1.5%	£78	4.9%	
single heated	£155		89.4%	£178		117.1%
double unheated	£81	1.0%		£77	6.1%	
double heated	£124		51.0%	£131		59.8%
low E unheated	£79	3.3%		£76	7.3%	
low E heated	£106		29.8%	£109		32.9%
110 east	total	% decrease on 110	%increase on 110	total	% decrease on 110	%increase on 110
110 basic house	£86					
single unheated	£88		1.9%	£83	3.5%	
single heated	£154		78.5%	£177		105.8%
double unheated	£85	1.0%		£81	5.8%	
double heated	£122		42.0%	£131		52.3%
low E unheated	£83	3.5%		£80	7.1%	
low E heated	£105		22.7%	£108		25.6%
110 south	total	% decrease on 110	%increase on 110	total	% decrease on 110	%increase on 110
110 basic house	£80			£80		
single unheated	£80		0.5%	£77	3.8%	
single heated	£136		70.2%	£163		103.8%
double unheated	£77	3.4%		£76	5.0%	
double heated	£106		32.5%	£118		47.5%
low E unheated	£75	6.2%		£75	6.3%	
low E heated	£92		14.4%	£99		23.8%
110 west	total	% decrease on 110	%increase on 110	total	% decrease on 110	%increase on 110
110 basic house	£86			£86		
single unheated	£87		1.2%	£83	3.5%	
single heated	£151		75.6%	£174		102.3%
double unheated	£85	1.2%		£81	5.8%	
double heated	£120		39.5%	£129		50.0%
low E unheated	£83	3.5%		£80	7.0%	
low E heated	£104		20.9%	£108		25.6%

The annual percentage comfortable hours for specific periods of the day

NORTH FACING	Percentage of morning hours which are comfortable	Percentage of afternoon hours which are comfortable	Percentage of evening hours which are comfortable	Percentage of morning+ afternoon hours which are comfortable [daytime]	Percentage of morning + afternoon + evening hours hours which are comfortable
INTEGRAL					
single	35	29	33	32	32
double	30	26	28	28	28
low E	28	25	24	26	26
SEMI-EXP'D					
single	36	30	33	33	33
double	31	26	30	29	29
low E	28	24	25	26	26
EXPOSED					
single	36	32	30	34	32
double	31	26	31	29	29
low E	28	23	28	26	26

The annual percentage comfortable hours for specific periods of the day

EAST FACING	Percentage of morning hours which are comfortable	Percentage of afternoon hours which are comfortable	Percentage of evening hours which are comfortable	Percentage of morning+ afternoon hours which are comfortable [daytime]	Percentage of morning + afternoon + evening hours hours which are comfortable
INTEGRAL					
single	30	27	31	29	30
double	27	26	25	26	26
low E	26	25	25	25	25
SEMI-EXP'D					
single	32	29	34	30	31
double	29	25	29	27	28
low E	26	23	25	25	25
EXPOSED					
single	32	32	31	32	32
double	30	26	33	28	30
low E	27	23	29	25	27

The annual percentage comfortable hours for specific periods of the day

SOUTH FACING	Percentage of morning hours which are comfortable	Percentage of afternoon hours which are comfortable	Percentage of evening hours which are comfortable	Percentage of morning+ afternoon hours which are comfortable [daytime]	Percentage of morning + afternoon + evening hours hours which are comfortable
INTEGRAL					
single	36	28	34	32	33
double	31	26	30	28	29
low E	28	25	31	27	28
SEMI-EXP'D					
single	36	27	33	31	32
double	31	23	30	27	28
low E	27	22	27	24	25
EXPOSED					
single	36	28	32	32	32
double	32	23	31	28	29
low E	25	20	28	22	24

The annual percentage comfortable hours for specific periods of the day

WEST FACING	Percentage of morning hours which are comfortable	Percentage of afternoon hours which are comfortable	Percentage of evening hours which are comfortable	Percentage of morning+ afternoon hours which are comfortable [daytime]	Percentage of morning + afternoon + evening hours hours which are comfortable
INTEGRAL					
single	33	26	27	30	29
double	28	24	24	26	26
low E	28	24	23	26	25
SEMI-EXP'D					
single	37	27	29	32	29
double	33	23	26	28	27
low E	23	23	24	25	24
EXPOSED					
single	36	28	29	32	31
double	36	23	29	29	29
low E	30	20	26	25	25

APPENDIX I

Approximate Cost of Glazing for the Glazed Spaces

Approximate Cost of Glazing for the Glazed Spaces

	area m^2	single walls	double roof	double walls	double roof	low E walls	low E roof
cost/m^2		£21	£62	£48	£62	£78	£109
single storey							
walls	25.1	£527		£1205		£1957	
roof	9.38		£582		£582		£1022
total		**£1109**		**£1786**		**£2979**	
two storey							
integral							
walls	13.6	£286		£653		£1061	
roof	12.7		£787		£787		£1384
total		**£1073**		**£1440**		**£2445**	
semi-exposed							
walls	29.6	£621		£1421		£2309	
roof	12.7		£787		£787		£1384
total		**£1408**		**£2208**		**£3693**	
exposed							
walls	48.9	£1027		£2347		£3814	
roof	12.7		£787		£787		£1384
total		**£1814**		**£3135**		**£5196**	

From figures supplied by Frost & Co, Conservatory Manufacturers
September 1995